DEPARTMENT OF INFORMATION ENGINEERING
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Reconfigurable Antennas and their Applications

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Funded By: **Cariparo Foundation**

November, 24, 2015

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Abstract

One of the biggest challenge in modern communication systems is to provide a single antenna for different applications. Existing antenna systems are limited to some applications. So it is important to design a single reconfigurable antenna for multiple applications.

Five different reconfigurable printed antennas for different applications are designed during the study of this thesis. In the first design an antenna for frequency reconfigurable applications is designed. The electrical length of the conductor is changed using PIN diodes and the resonance of antenna is shifted from 4.27 GHz to 3.56 GHz. Good agreement between simulated and measured results is observed. In the second and third designs, Ultra wideband (UWB) Multiple-Input Multiple-Output (MIMO) antennas with on-demand Wireless Local Area Network (WLAN) rejection are designed. The second design consists of two elements UWB-MIMO antenna and stubs are connected to the ground plane using PIN diodes. These stubs act as a stop-band filter and reject the band at 5.5 GHz center frequency. This design has a compact size of 23 x 39.8 mm^2. The third design has almost same [redacted] as of second design but it has four elements. These elements are placed orthogonally to each [redacted] The total size of this proposed design is 50 x 39.8 mm^2. The ground plane is common and a band-stop [redacted] is placed between the ground planes. This band-stop design is connected with the ground plane [redacted] PIN diodes. When diodes are biased, the current is travelled to the nearly placed band-stop design and [redacted] obtained around 5.5 GHz. In fourth design a reconfigurable array with a sensing circuit is [redacted] array consists of four individual reconfigurable patches which are attached to the different [redacted]. These patches are reconfigured from 3.15 GHz to 2.43 GHz using PIN diodes. The correct [redacted] element is provided using phase shifters. The sensing circuit is designed in such a way that [redacted] is changed to provide the correct phase on the switching frequency. The patterns of the [redacted] on both switching frequencies when array is attached to wedge or cylindrical surface. [redacted] series-fed array is designed. Composite Right/Left Handed Transmission Line (CRLH-TLs) [redacted] meanderline microstrip lines to connect the array elements. These CRLH-TLs [redacted] each connecting element, which resulted in broad side radiation patterns. [redacted] to another frequency a small patch and second CRLH-TL is connected between [redacted]

[redacted] PIN diodes, Selflex Antennas, CRLH antenna arrays, UWB-MIMO antennas

Biography

Muhammad Saeed Khan in a researcher at ETIC research center and Research affiliate of Department of Information Engineering, University of Padova, Italy. He received his B.Sc. degree in electrical (telecom) engineering from COMSATS Institute of Information Technology, Islamabad, Pakistan, in 2011. Based on his achievement during his B.Sc. degree, he was awarded EMMA WEST Exchange Scholarship for his B.Sc. mobility Program. He received his Ph.D. degree in 2016 from University of Padova, Italy. He was also recipient of a fully funded Ph.D. scholarship from Cariparo Foundation which provides scholarship to top 15 candidates from all over the world. During his Ph.D. he also spent 18 months at North Dakota State University, USA as a visiting scholar. He was Head of Department of Electrical Engineering Department of Riphah International University, Lahore Campus for one year (2015-2016). His current research interests include advanced techniques and technologies for Antenna design for medical applications, Phased array for radar systems, Reconfigurable antennas for advance applications, UWB-MIMO antennas and novel material based antennas. During this short period of time, he is author-coauthor of more than 40 peer-reviewed journal or conference papers.

Outline

- **Background**
  - Printed Antennas
  - Reconfigurable Antennas
  - Previous Work
- **Conducted Research**
  - Research question
  - Diode Model in Simulation
  - Proposed Designs
- **Conclusion, challenges and Future Directions**

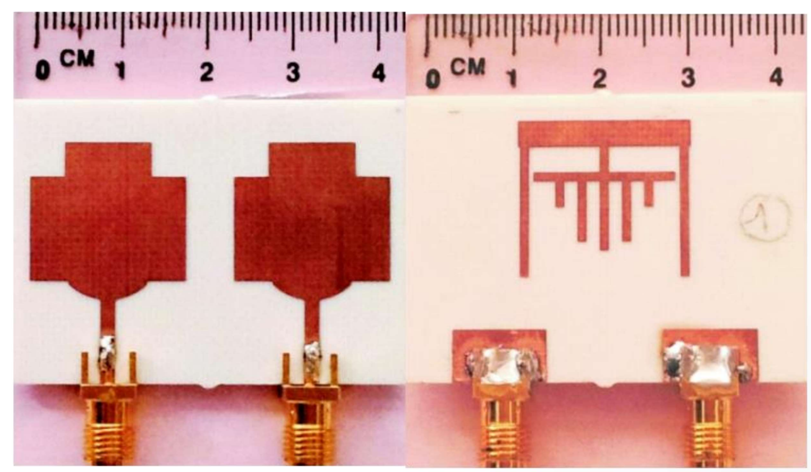
Background of Printed Antennas

➢ Advantages of Printed Antennas

- light weight
- small size
- most useful at microwave frequencies (f > 1 GHz)
- a wide range of radiation patterns
- typical applications are single element and arrays

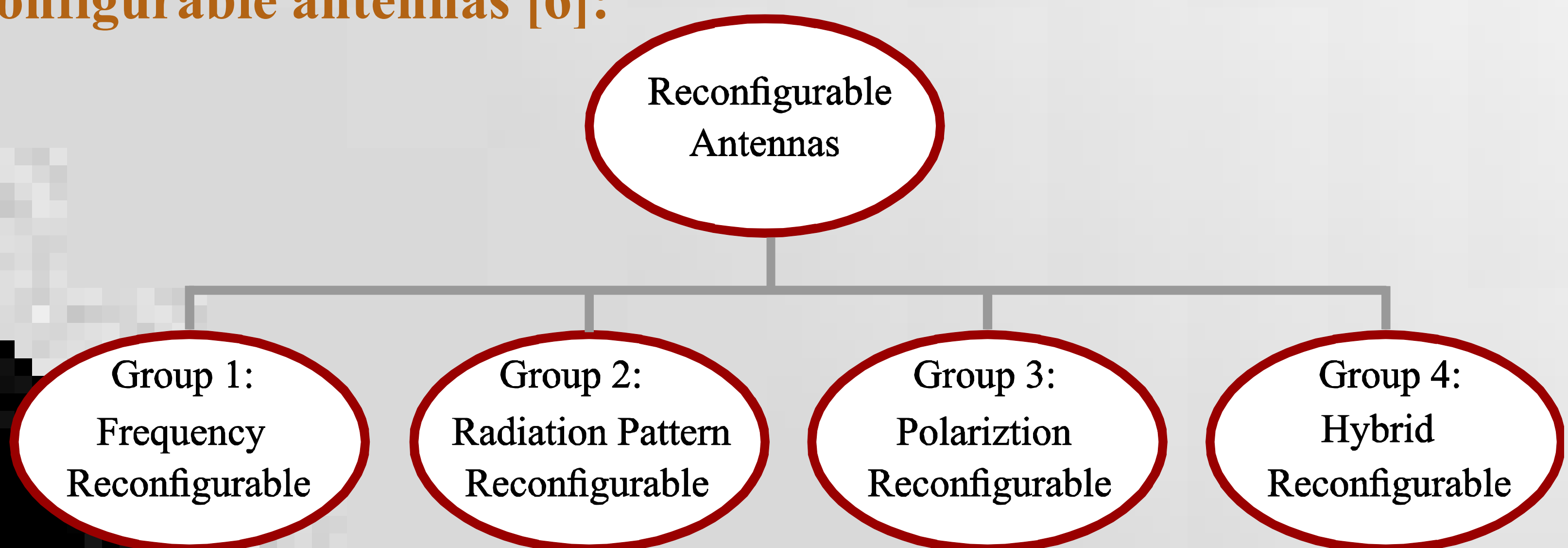
➢ History of Printed Antennas

- Deschamps's in 1953 [1]
- detailed by Alexopoulos [2]
- work by Munson 1972 [3]



Background of Reconfigurable Antennas

- **Reconfigurability means changing the fundamental operating characteristics of an antenna using electrical, mechanical or other means.**
  - First patent reported in 1983 by Schaubert. [4]
  - In 1999, a multi university program was launched by Defense Advanced Research Projects Agency (DAPRA) to investigate reconfigurable antennas and their applications. [5]
  - A hot topic of interest these days.
- **Types of Reconfigurable antennas [6]:**



Techniques for reconfigurable operation

- **Electrically reconfigurable antennas**
  - Using RF-MEMS [7]
  - Using PIN diodes [8]
  - Using varactors [9]
- **Optically reconfigurable antennas**
  - Using nonintegrated optical fibers [10]
  - Using integrated optical fibers [11]
  - Using integrated LASER diodes [12]
- **Physically reconfigurable antennas**

Some examples of Reconfigurable Antennas

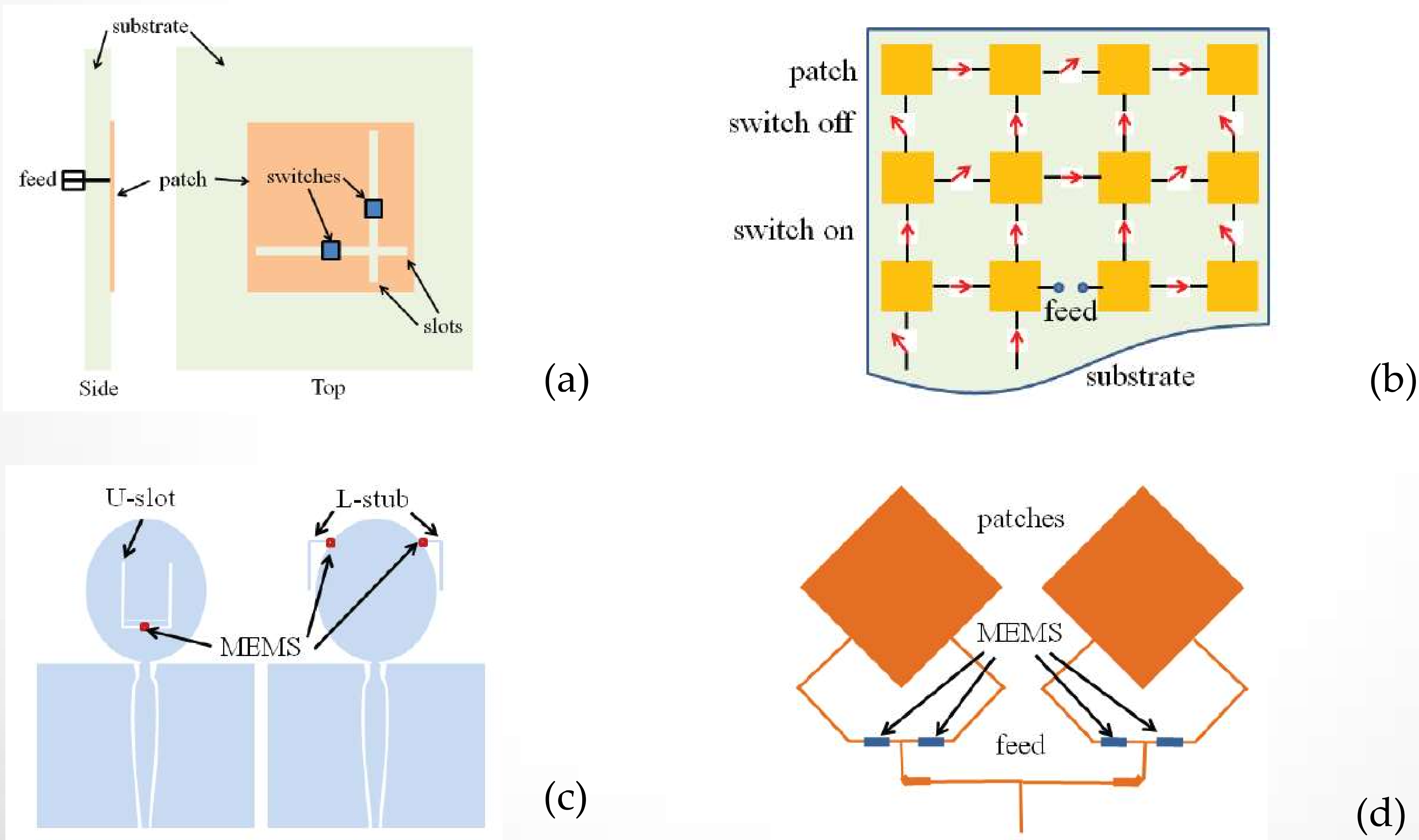


Figure: Source: R. L. Haupt and M. Lanagan, "Reconfigurable Antennas," *IEEE Antennas and Propagation Magazine,* Vol. 55, No. 1, February 2013.

A Comparison of Electrical Properties

Table 1. Comparison of electrical properties.

Electrical Property	RF MEMS	PIN Diode	Optical Switch
Voltage (V)	20-100	3-5	1.8-1.9
Current (mA)	0	3-20	0-87
Power Consumption (mW)	0.05-0.1	5-100	0-50
Switching Speed	1-200 μsec	1-100 nsec	3-9 μsec
Isolation (1 to 10 GHz)	very high	high	high
Loss dB (1 to 10 GHz)	0.05-0.2	0.3-1.2	0.5-1.5

Table 1. Source: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6178263

Proposed research

RESEARCH QUESTIONS:

- **How to implement re-configurability to some novel printed antennas which are not studied before?**

and

- **What are the trade-offs in the designing of such antenna arrays?**

Design of Diode Model in Simulation

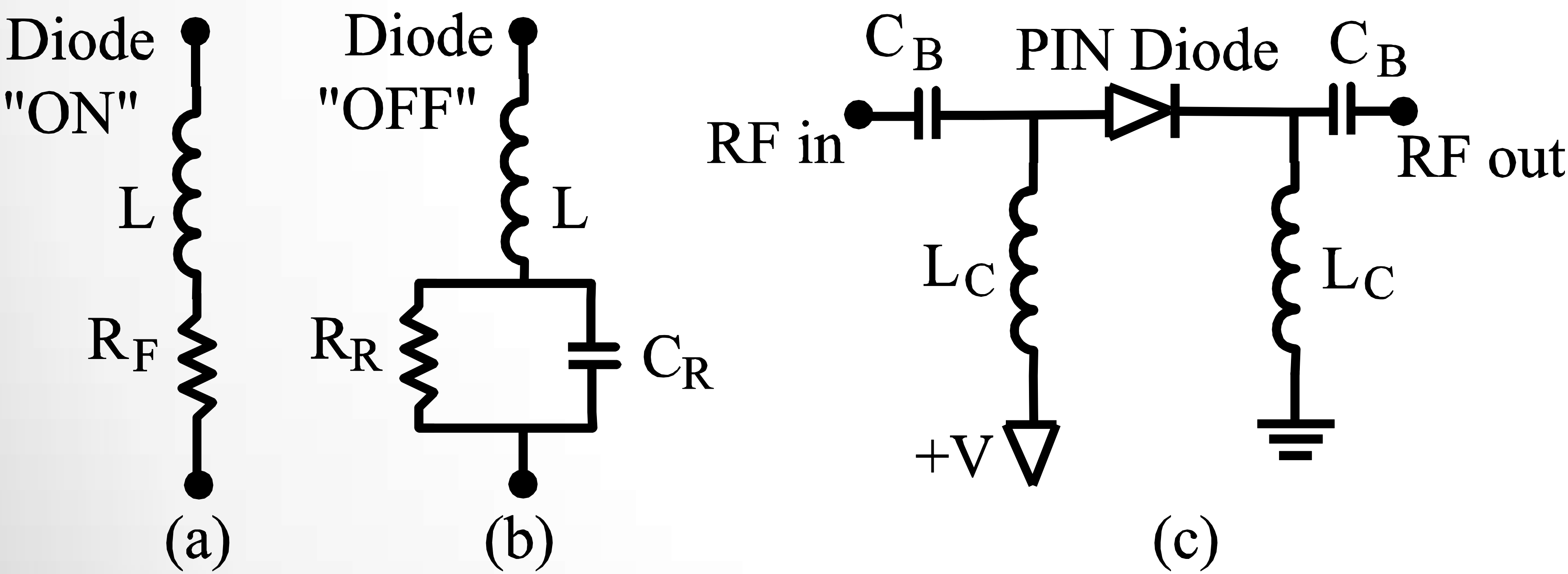


Figure: RF PIN diode: (a) Equivalent circuit model for “ON" conguration; (b) Equivalent circuit model for “OFF" conguration; (c) Biasing Network with PIN diode and RF choke model. Parameters are $L = 0.5\ nH$; $R_F = 0.8\ \Omega$; $R_R = 1k\ \Omega$; $C_R = 0.01\ pF$; $C_B = 45\ pF$; $L_C = 200\ nH$:

Diode Design in Simulation

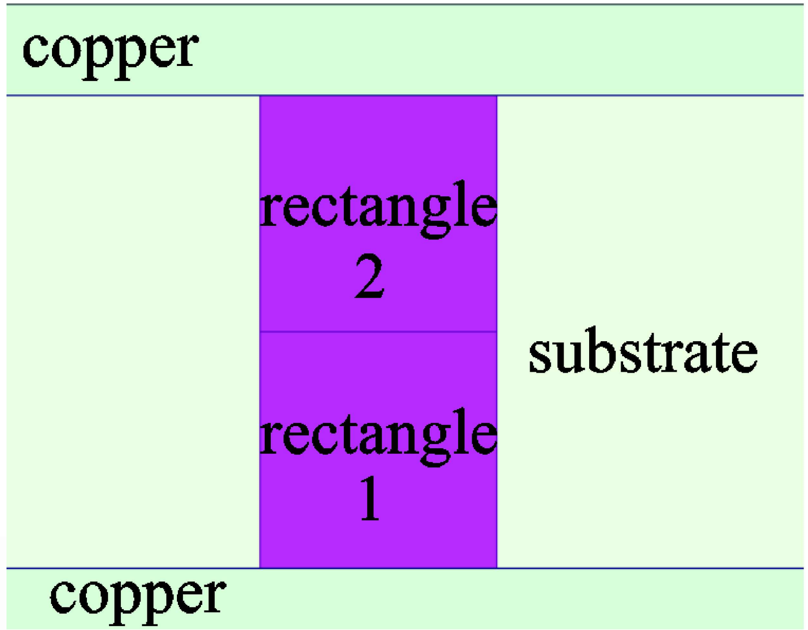
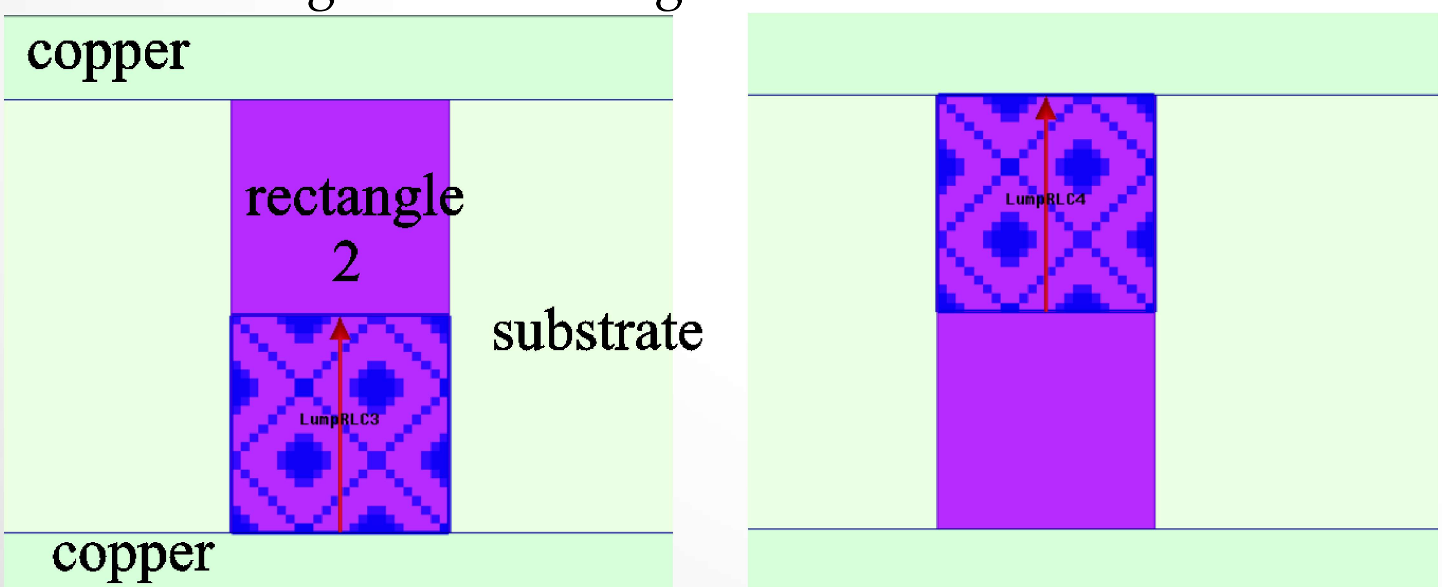


Figure: Modelling of PIN diode in HFSS



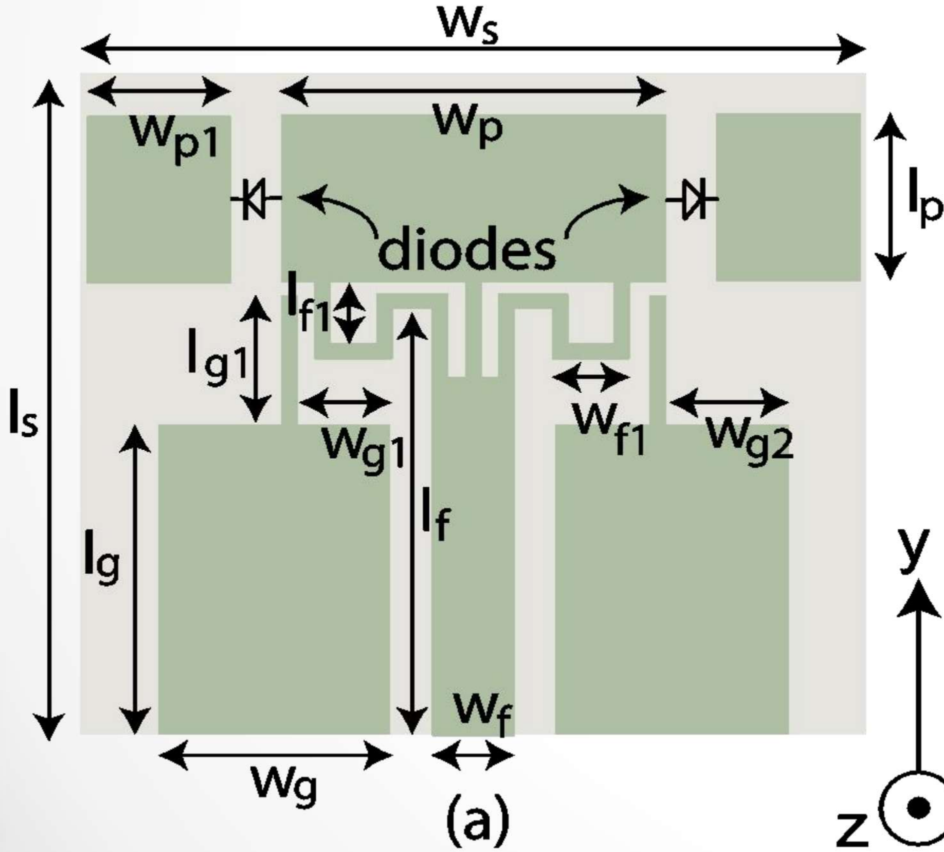
(a) (b)

Figure: Modelling of PIN diode in HFSS. (a) Assigning first lumped element. (b) Assigning second lumped element.

Proposed Design 1

➢ **Frequency reconfigurable Antennas**

- Dimensions are 14.5 x 12.8 mm^2
- Frequency shift from 4.27 GHz to 3.56 GHz
- Gain reduced from 1.3 dBi to 0.2 dBi



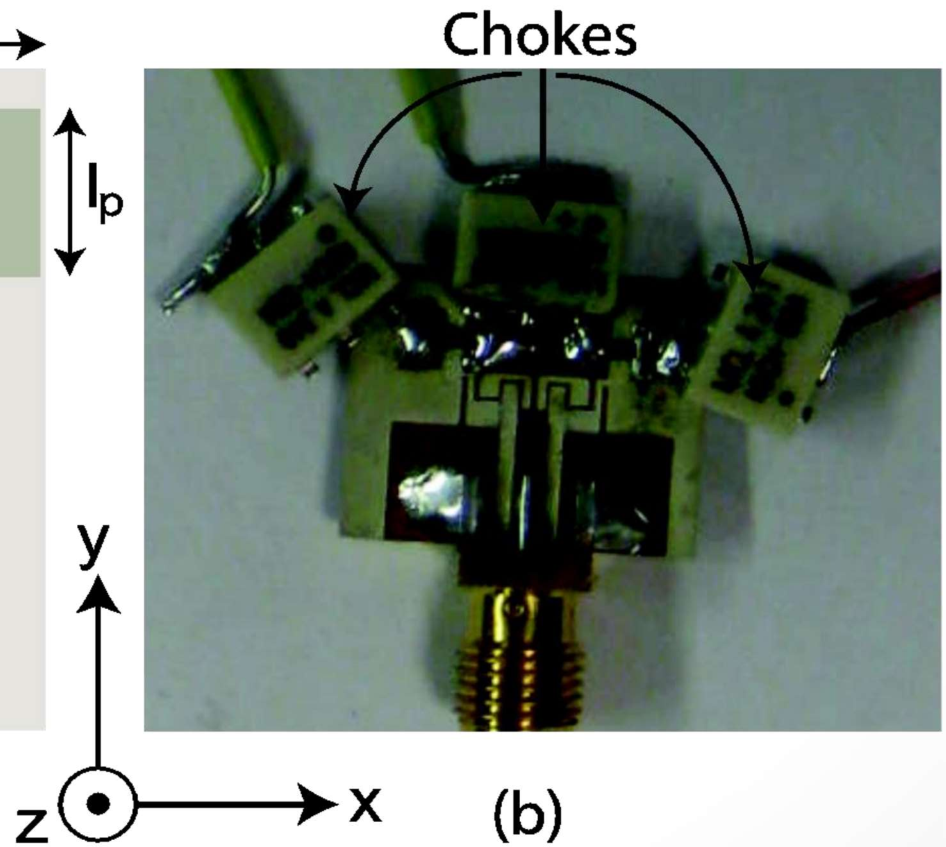


Figure: (a) Layout of the proposed antenna with dimensions, (b) Fabricated photograph. Optimized dimensions in mm are: $w_s = 14.5$; $l_s = 12.8$; $w_p = 7$; $w_{p1} = 2.25$; $l_p = 3$; $w_g = 4.25$; $w_{g1} = 1.5$; $w_{g2} = 2.25$; $l_g = 7$; $l_{g1} = 1.5$; $w_f = 1.5$; $l_f = 8.3$; $w_{f1} = 1$; $l_{f1} = 1$;

Simulated and Measured Results

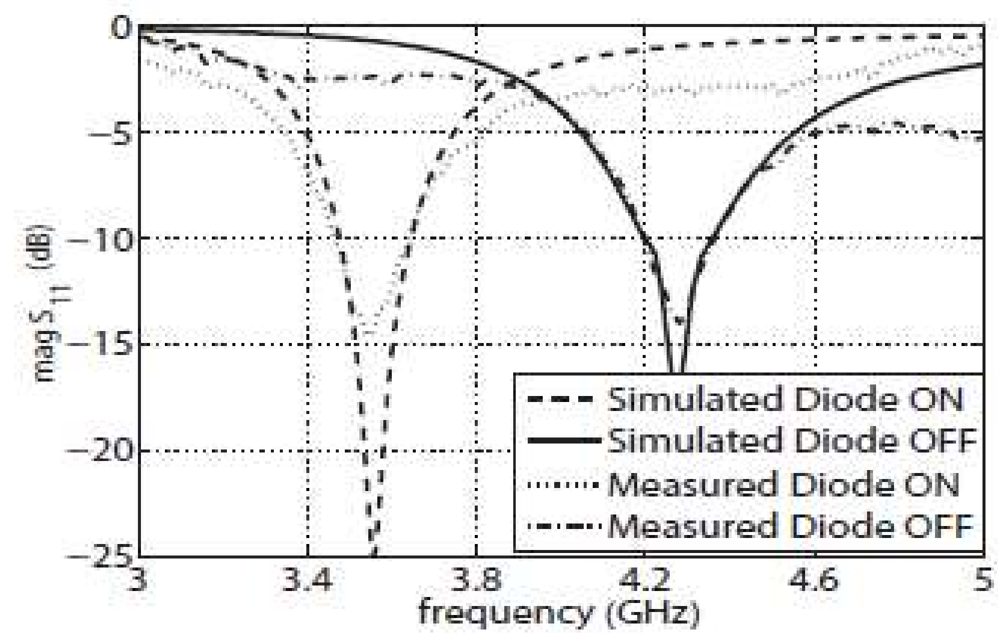


Figure: Measured reflection coefficient.

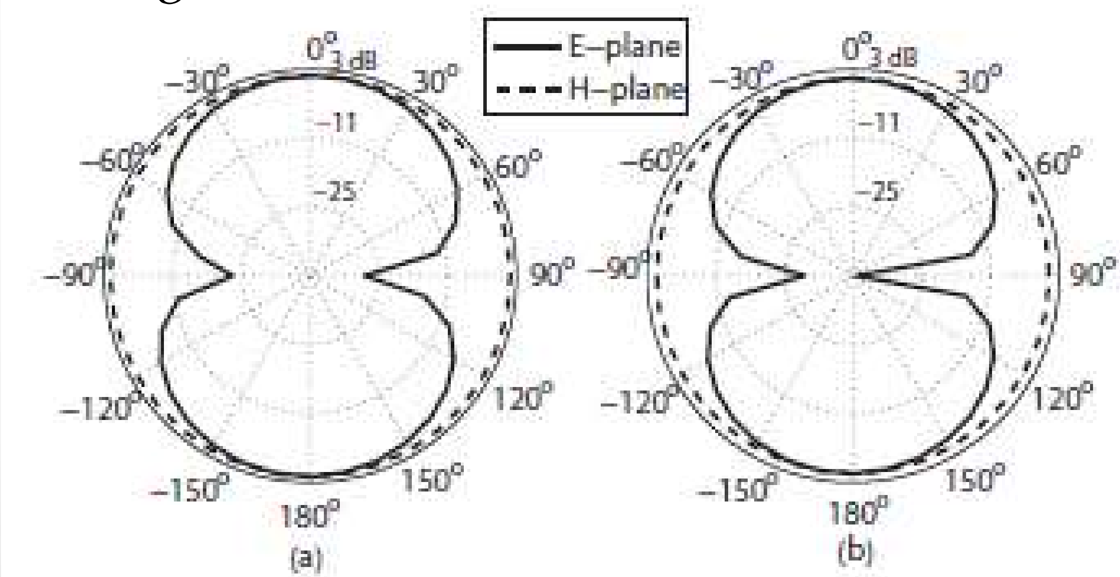


Figure: Measured radiation Patterns in E-plane and H-plane (a) 4.27 GHz (b) 3.56 GHz.

Proposed Design 2

- **Two Elements UWB-MIMO antenna**
  - Dimensions are 23 x 39.8 mm^2
  - Frequency from 2 to 12 GHz for OFF state
  - Rejects the band from 4.8 to 6.4 GHz in the ON state.
  - One design with common ground plane and one design with separate ground plane
  - Fabricated on Rogers TMM4 substrate
  - PIN diodes are used on the ground plane to connect lamda/4 stubs

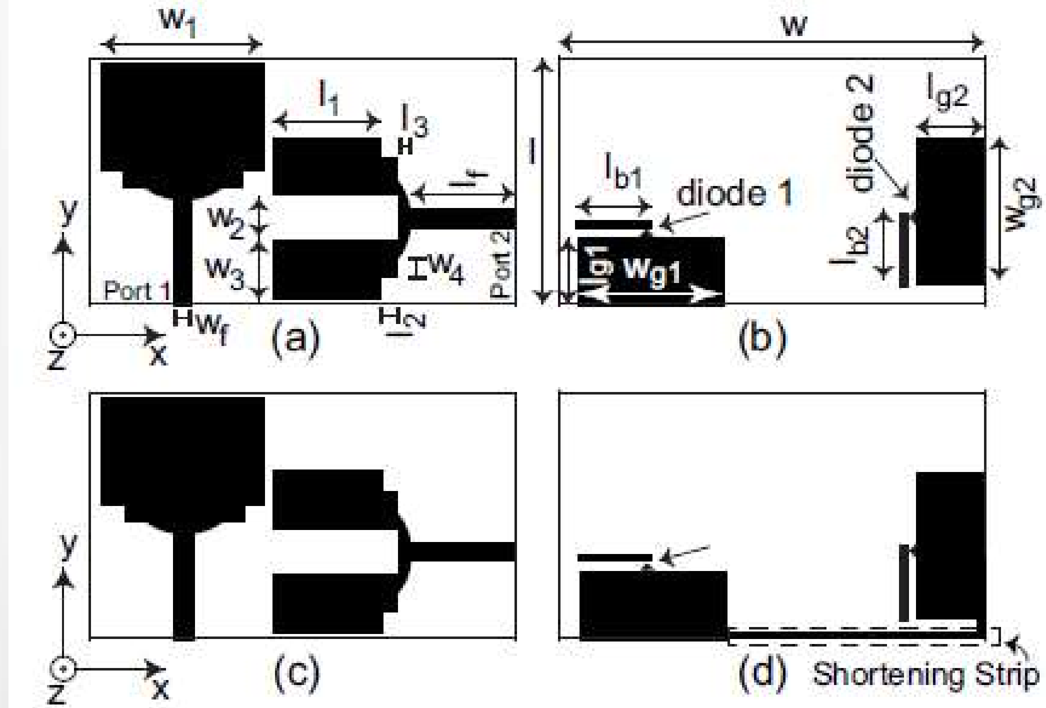


Figure: Geometry of proposed UWB-MIMO system. (a) top view (b) bottom view with separate ground planes (c) top view (d) bottom view with shared ground plane.

...of proposed antenna (a) top view, (b) bottom view without common ground. Optimized ...9.8 *mm*; $l = 23$ *mm*; $w_1 = 15$ *mm*; $w_2 = 4$ *mm*; $w_3 = 5.5$ *mm*; $w_4 = 2.26$ *mm*; $l_1 = 10$ *mm*; $l_2 = 1.5$ *mm*; l_3 ... $= 9.85$ *mm*; $w_{g1} = w_{g2} = 13.5$ *mm*; $l_{g1} = l_{g2} = 6.25$ *mm*; $l_{b1} = l_{b2} = 6.25$ *mm*:

Comparison of Simulated and Measured S-parameters

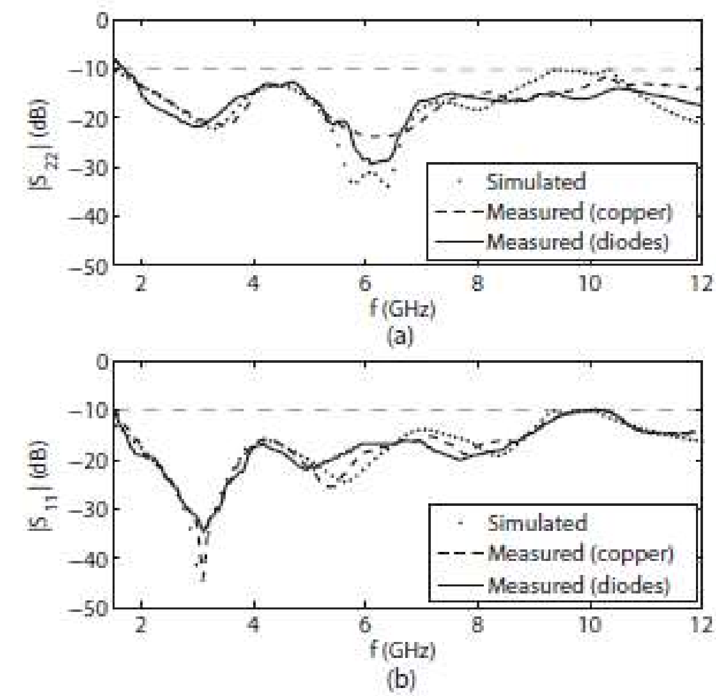
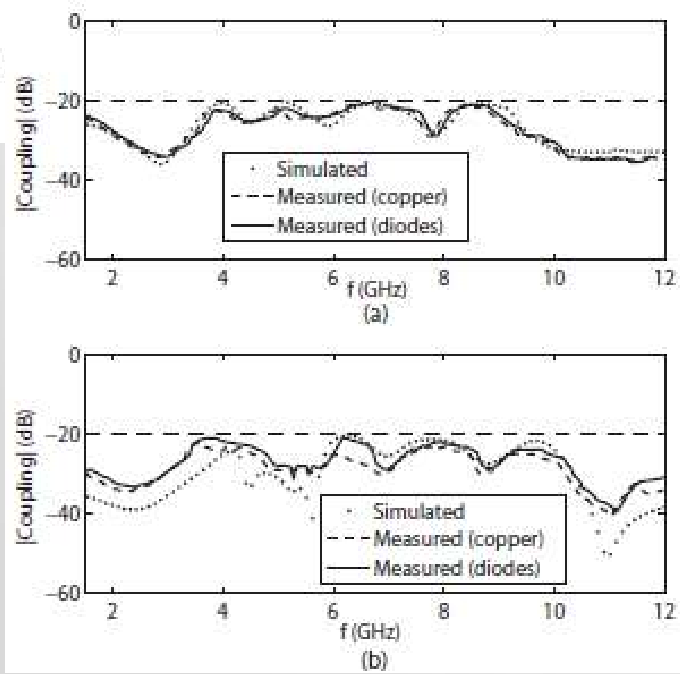


Figure: (a) $|S_{22}|$ and (b) $|S_{11}|$ the prototype when both ...des are "OFF".



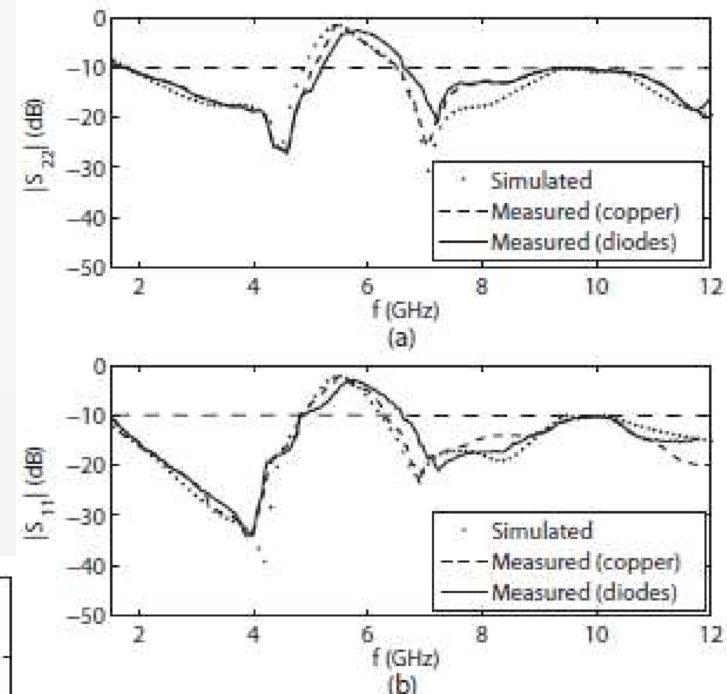
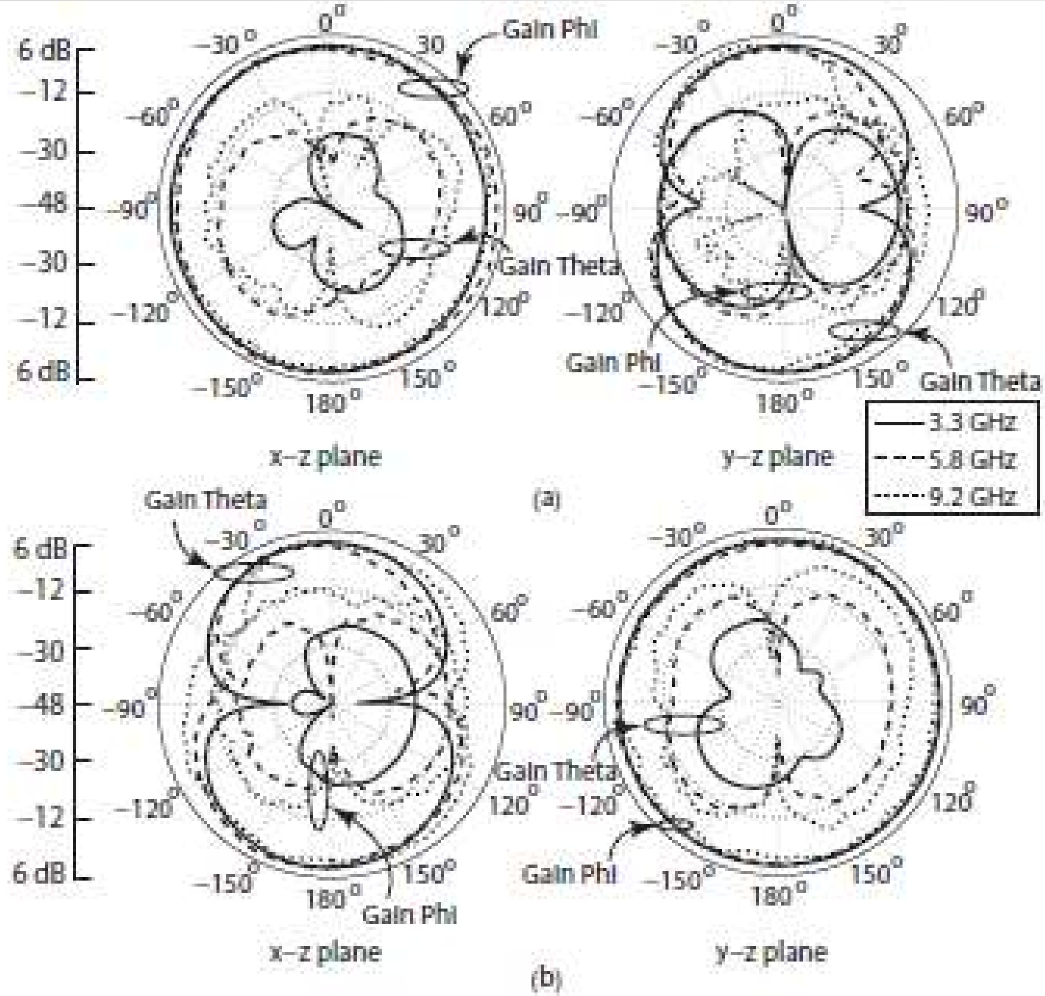


Figure: (a) $|S_{22}|$ and (b) $|S_{11}|$ of the prototype when both diodes are "ON".

- ...ling between the ports for the diodes (a) "OFF" and (b) "ON".

Radiation Patterns



[redacted]ation patterns at 3 [redacted]z, when both [redacted]t 1 being driven

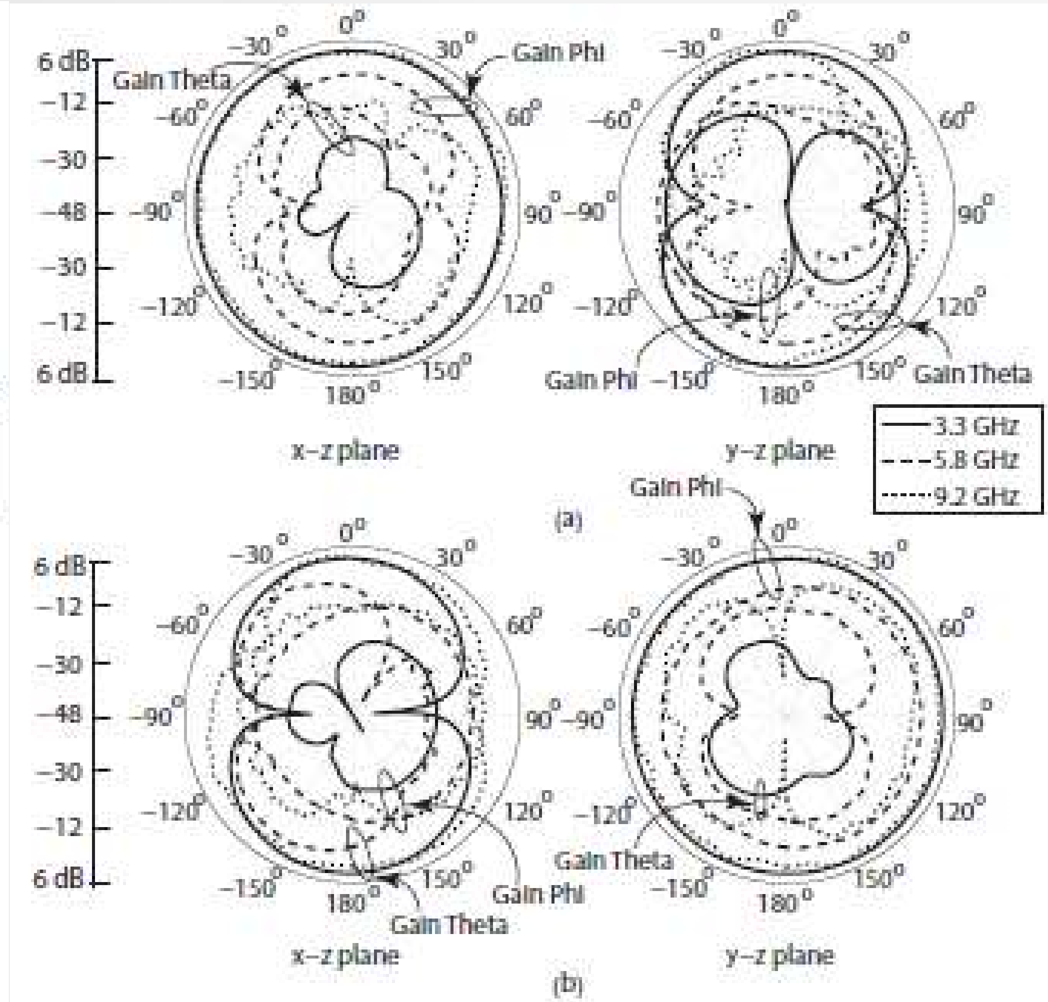
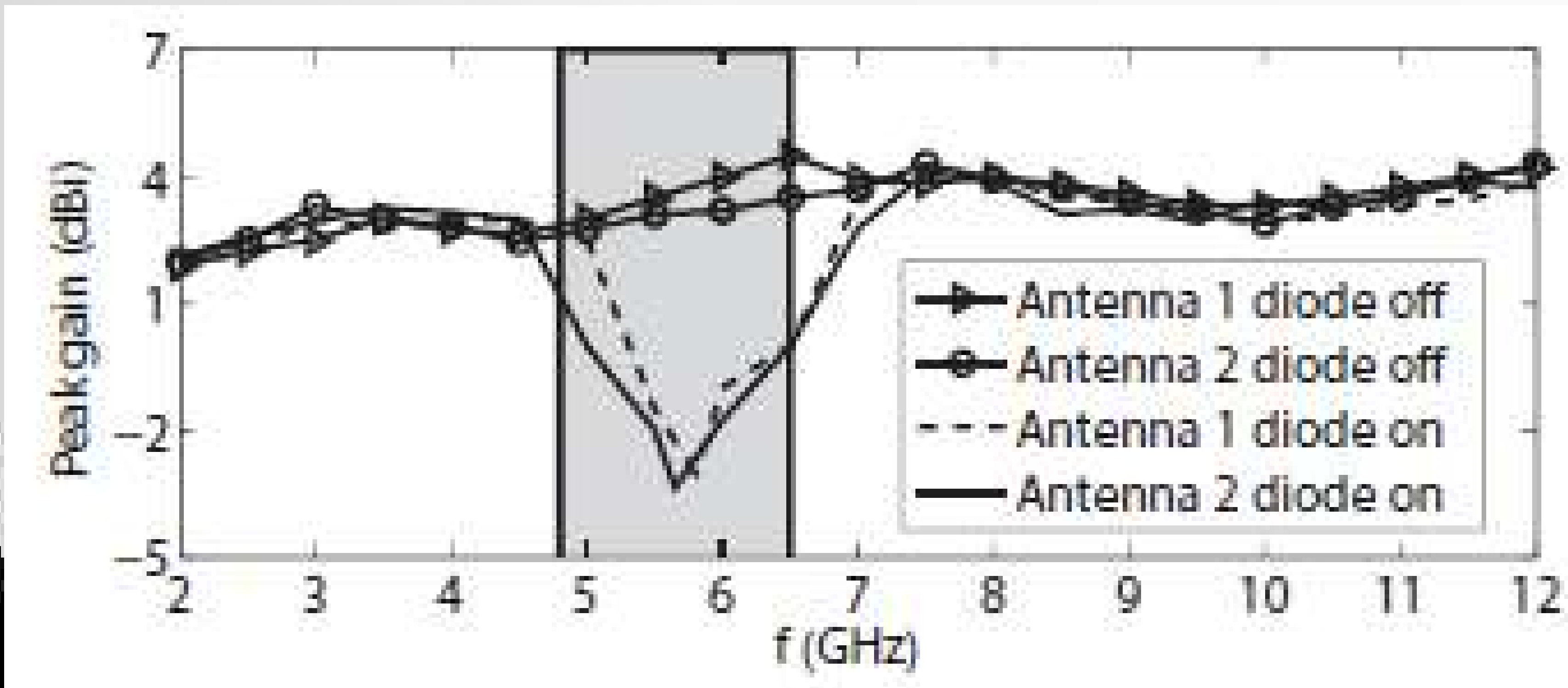


Figure: Measured radiation patterns at 3 GHz, 5.8 GHz and 9.2 GHz, when both diodes are “ON" for (a) port 1 being driven and (b) port 2 being driven.

Radiation patterns and Peak Gain

- Different from traditional monopole at higher frequencies
- Due to presence of other radiator.
- Intensity of patterns is lower when diodes are ON
- Gain reduces from 3 dBi to -3.4 dBi, when Diodes are ON.
- Gain varies from 1.89 to 4.4 dBi

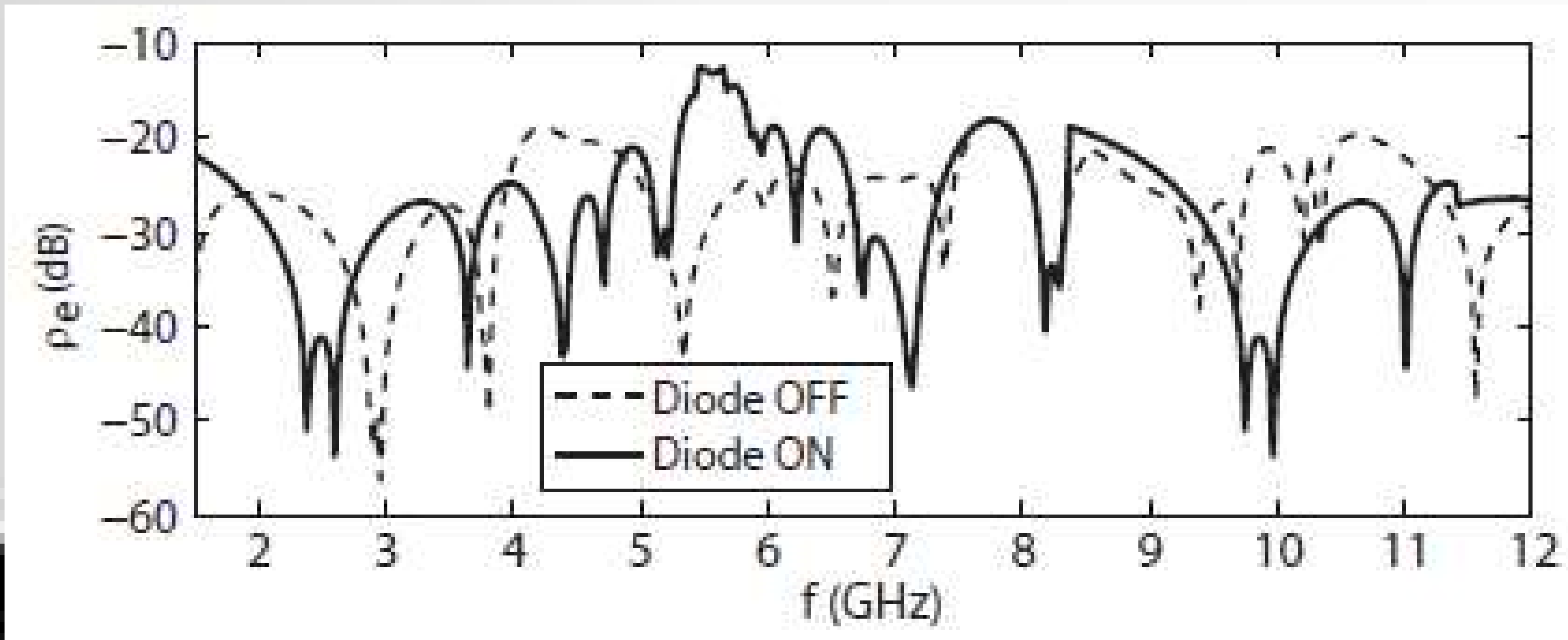


41. Measured Peak gain over the complete spectrum for the “OFF-
“ON-ON" states.

Envelope Correlation Coefficient

- ECC tells how much both antennas are correlated
- Less than -20 dB

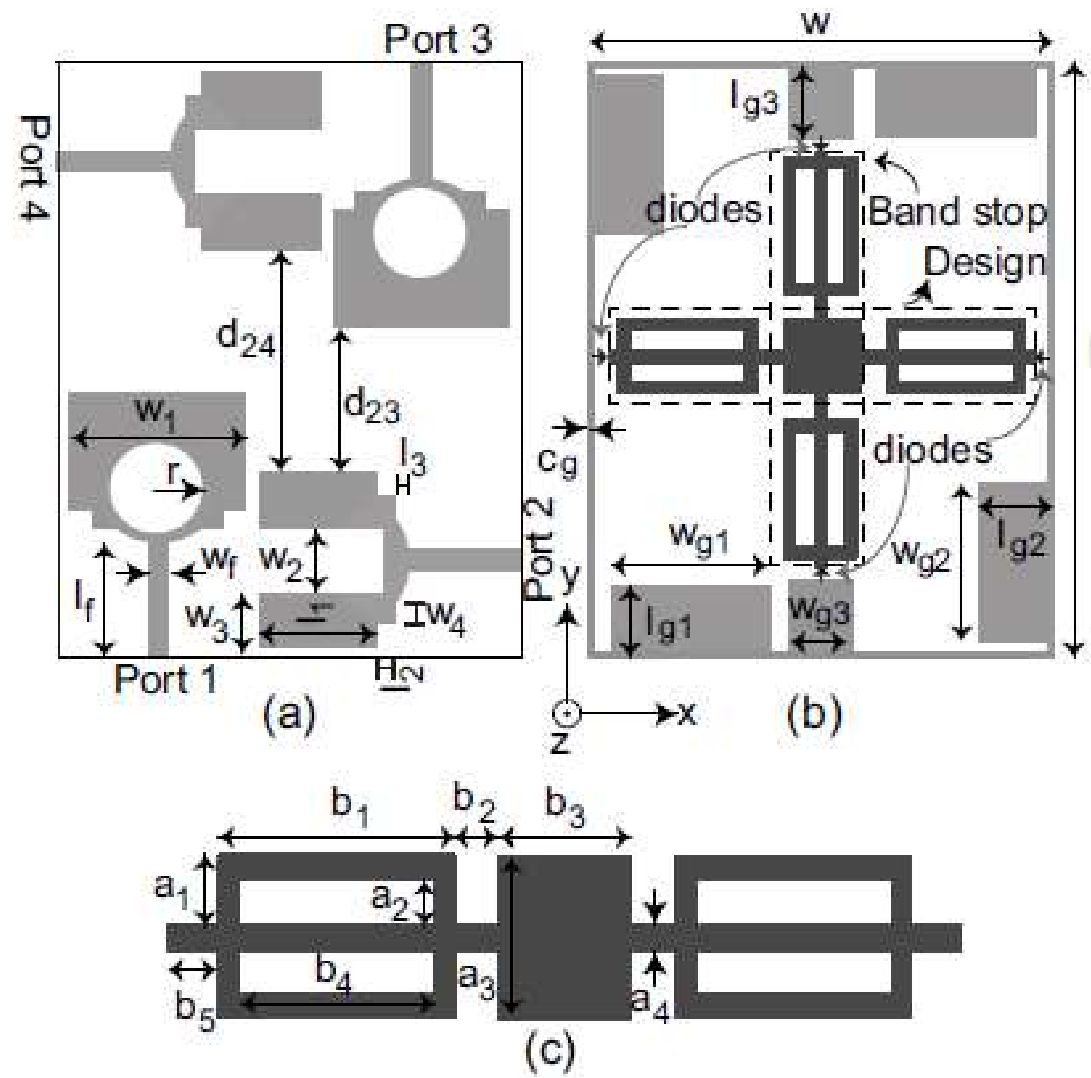
$$\rho_e = \frac{|S_{11}^* S_{12} + S_{21}^* S_{22}|^2}{(1 - |S_{11}|^2 - |S_{21}|^2)(1 - |S_{22}|^2 - |S_{12}|^2)}.$$



...re: Numerically calculated envelop correlation coefficient from ...ed S-parameters.

Proposed Design 3

- **Four Elements UWB-MIMO antenna with band stop design**
  - Dimensions are 50 x 39.8 mm^2
  - Bandwidth from 2.7 to 12 GHz, when diodes are ON, the band from 5.2 to 5.8 GHz is rejected.
  - [redacted]IN diodes are used to [redacted]nnect the band stop [redacted]n with ground plane



[redacted] of the proposed UWB-MIMO antenna (a) Top view (b) Bottom view [redacted]gn. Optimised dimensions in millimetres are: w = 39.8, l = 50, w_1 = [redacted], l_1 = 10, l_2 = l_5, l_3 = 1.1, w_f = 1.5, l_f = 9.85, d_{23} = 12, d_{24} = 18.95, [redacted] l_{g2} = 6.25, l_{g3} = 5.1, c_g = 0.5, a_1 = 2, a_2 = 1, a_3 = 5, a_4 = 1, b_1 = [redacted] b_5 = 0.5.

Surface Current Distribution

- When port 1 is excited and diodes are ON. The current passes to the band-stop design which is along the direction of antenna 1 and near to its ground plane
- Small current is induced on the nearly placed elements.
- High isolation due to orthogonal polarization

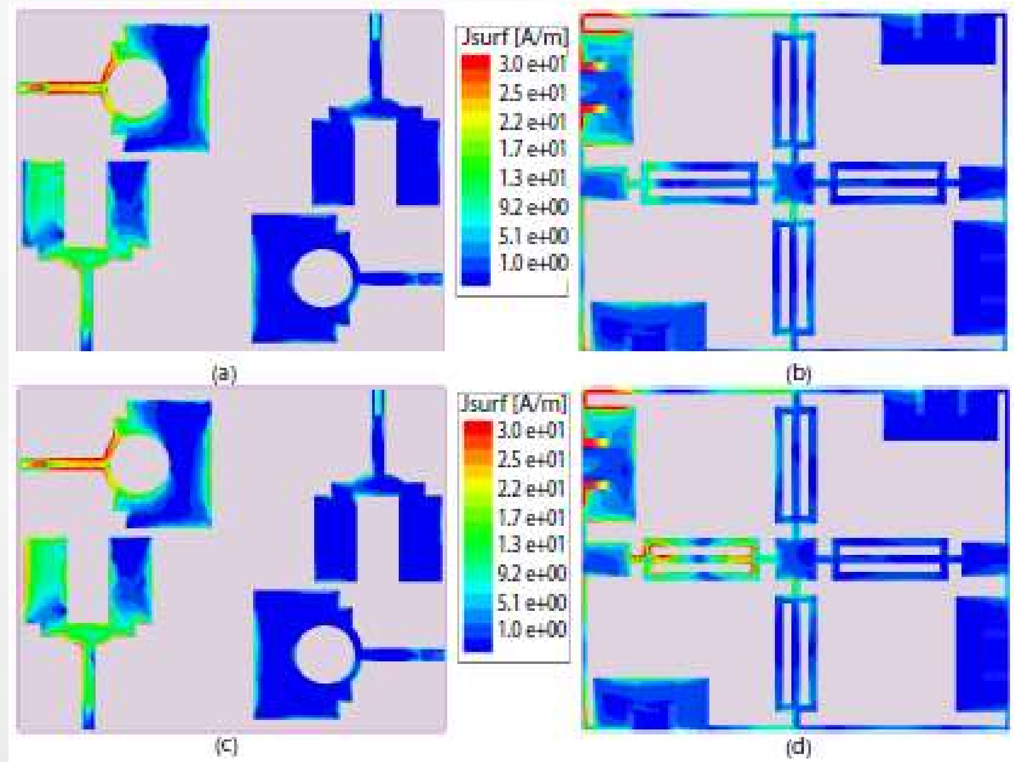


Figure: Simulated surface current distribution at 5.5 GHz, when port 1 is excited for the unbiased state (a) Top view (b) Bottom view, for the biased state (c) Top view (d) Bottom view.

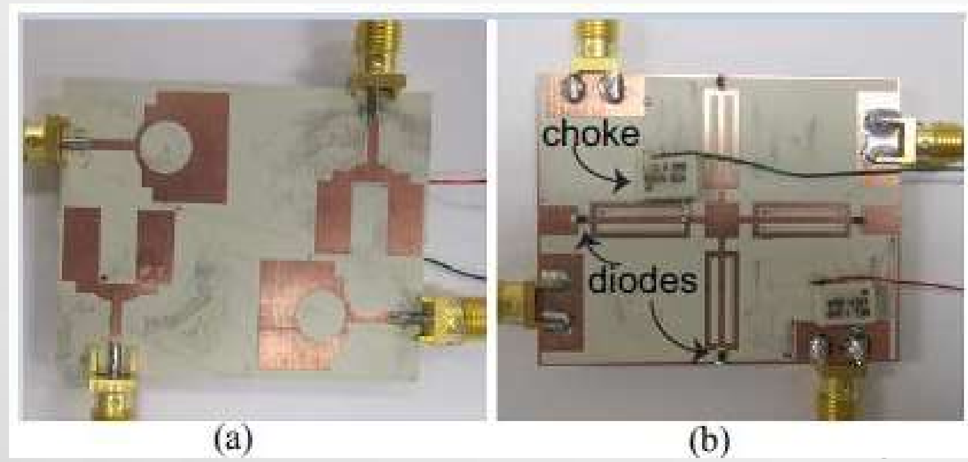
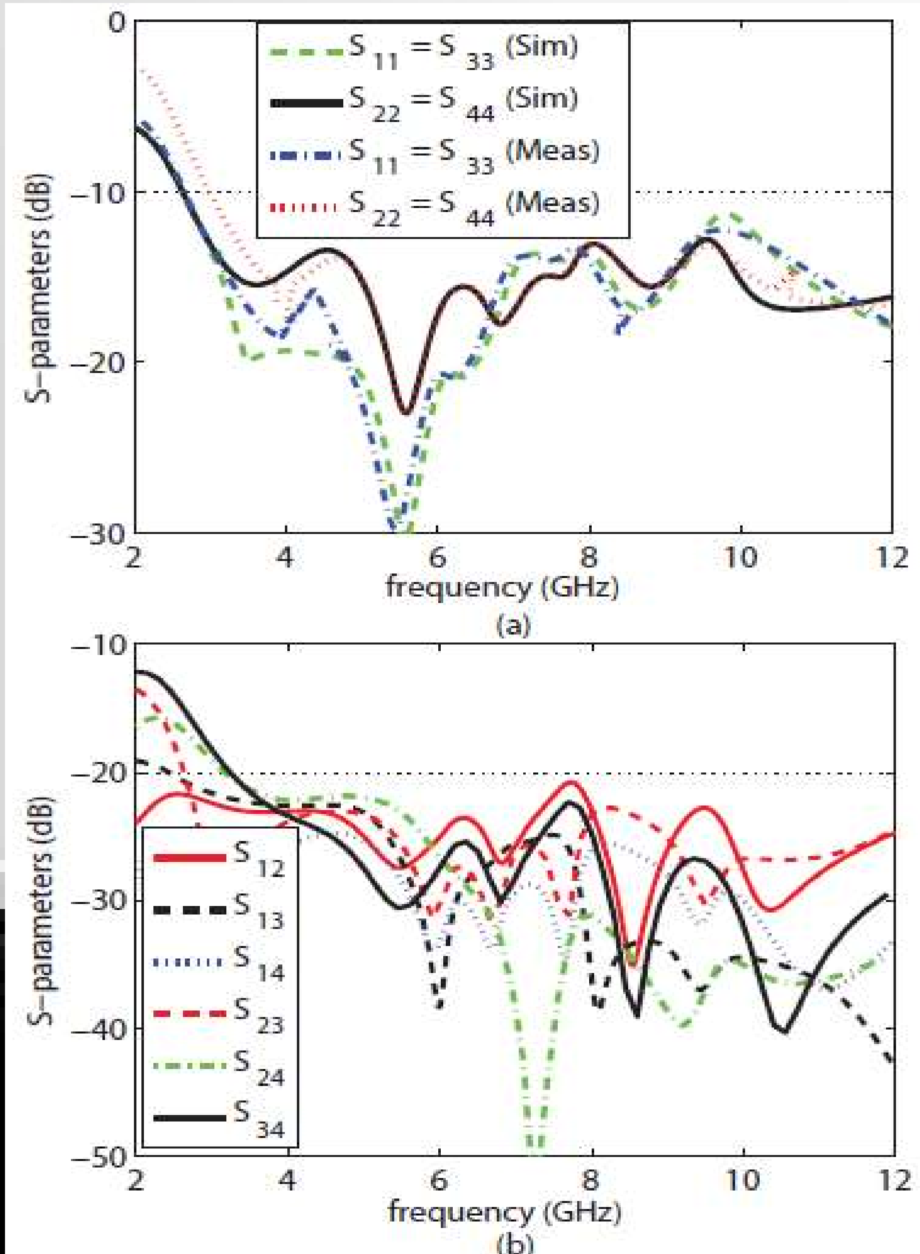


Figure: (a) Top view of the fabricated prototype (b) Bottom view

Simulated and Measured Results



[illegible] and measured S-parameters of [illegible] diodes unbiased states (a) S_{11} and [illegible] coupling

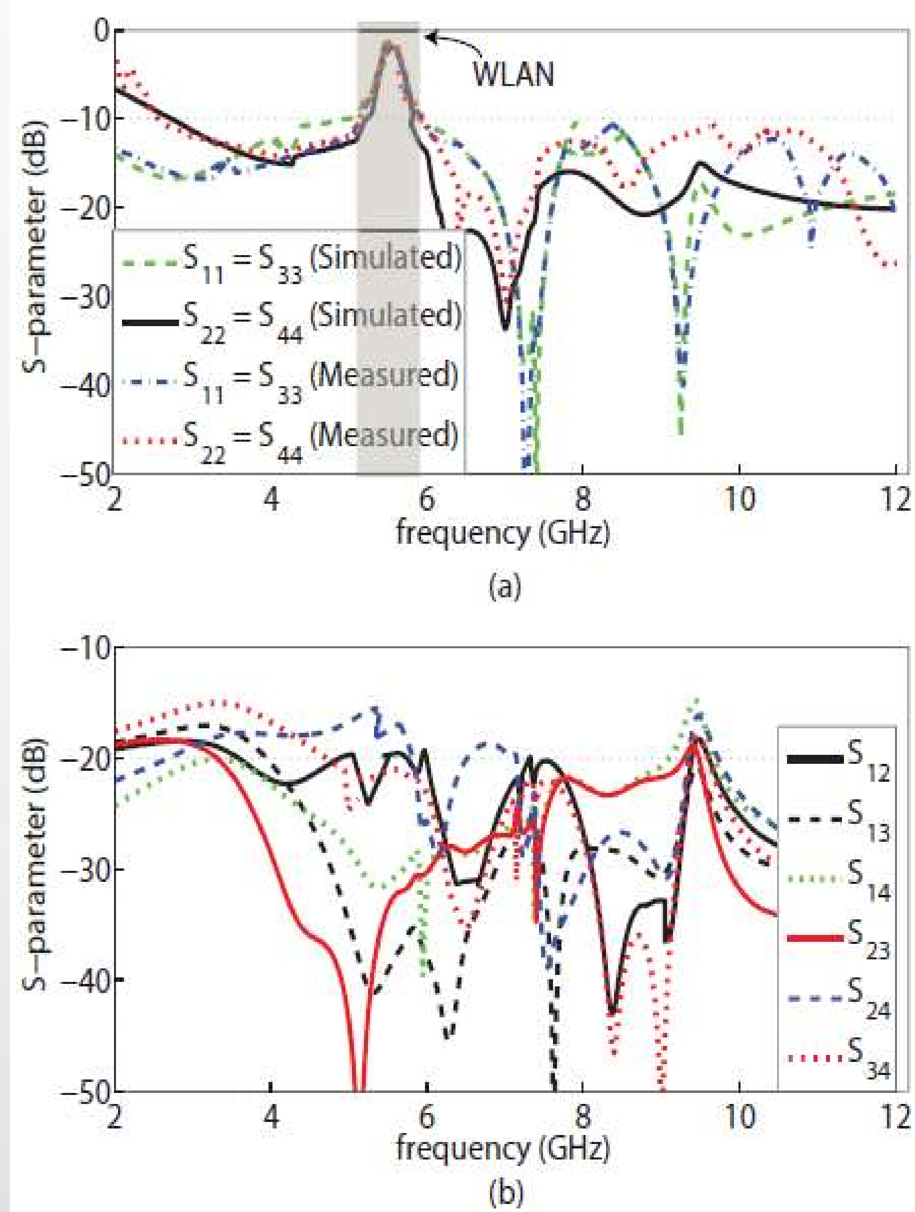
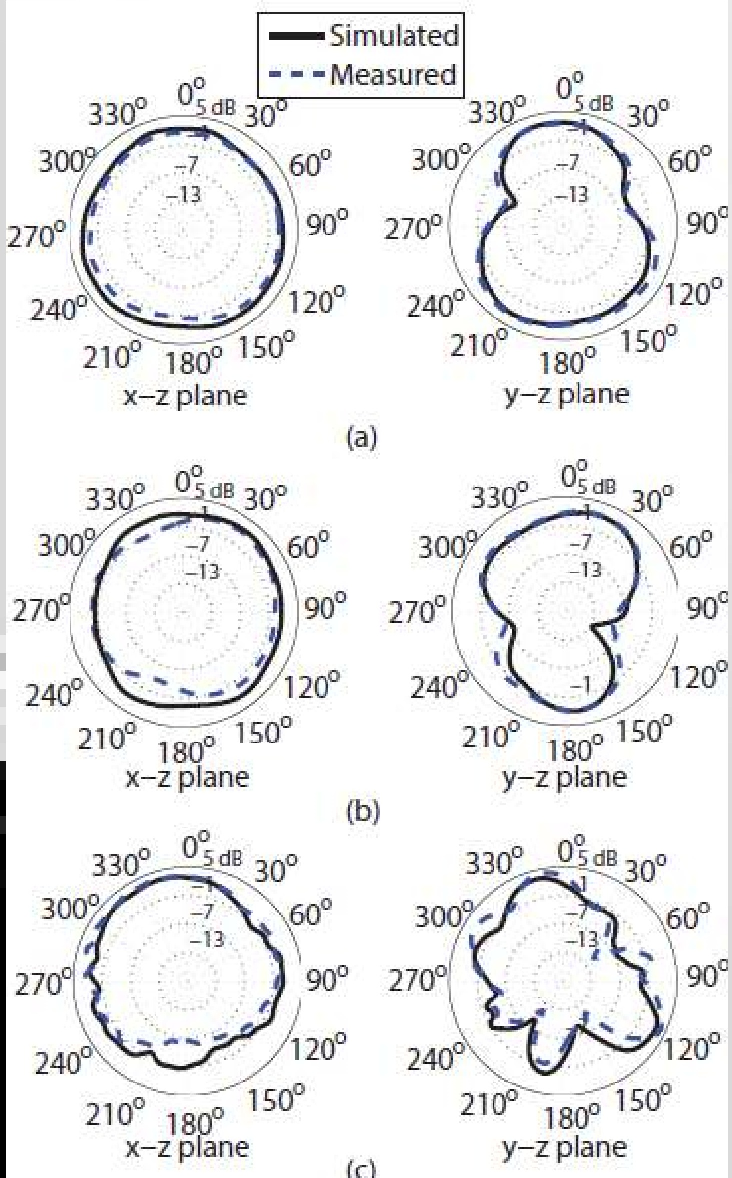


Figure: Simulated and measured S-parameters of antenna for the PIN diodes biased states (a) S_{11} and S_{22} (b) Measured mutual coupling

Radiation pattern



…d radiation patterns of
…diodes unbiased
…GHz, (b) 5.5 GHz,

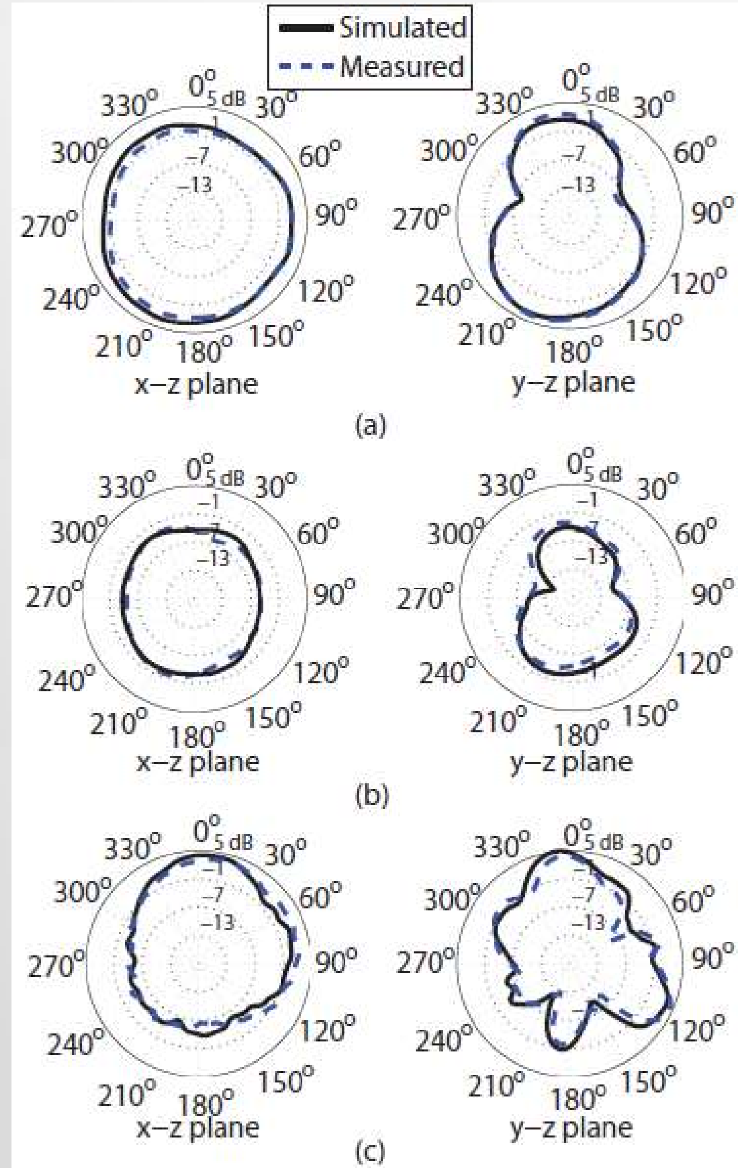
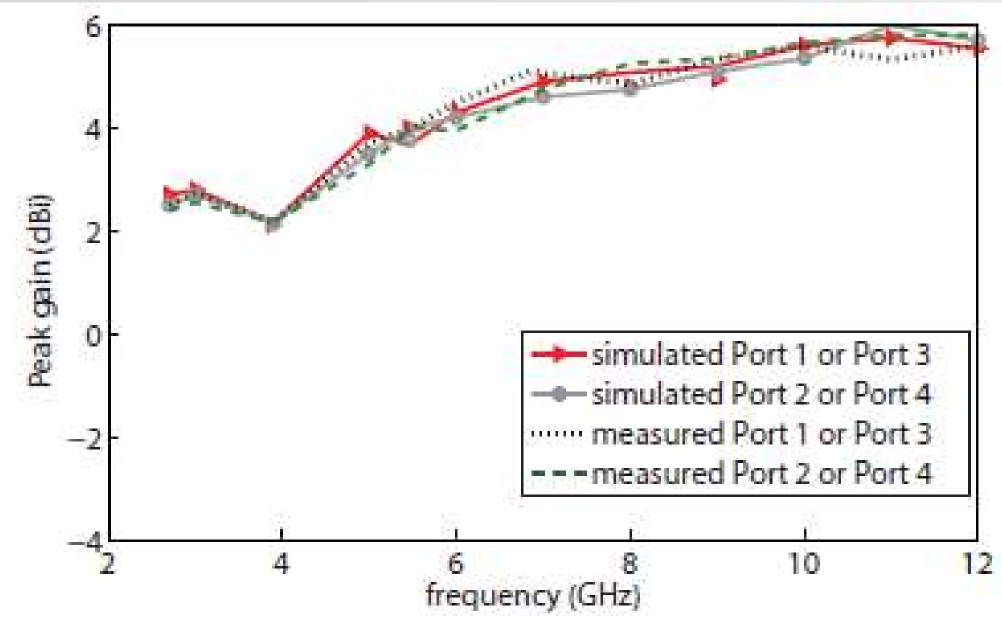


Figure : Simulated and measured radiation patterns of the proposed antenna for the PIN diodes biased states, only port 1 was excited (a) 3 GHz, (b) 5.5 GHz, and (c) 9 GHz.

Peak Gain and ECC



[illegible]re: Simulated and measured peak gain of the [illegible]ed antenna for the PIN diodes unbiased states [illegible]plete radiating band.

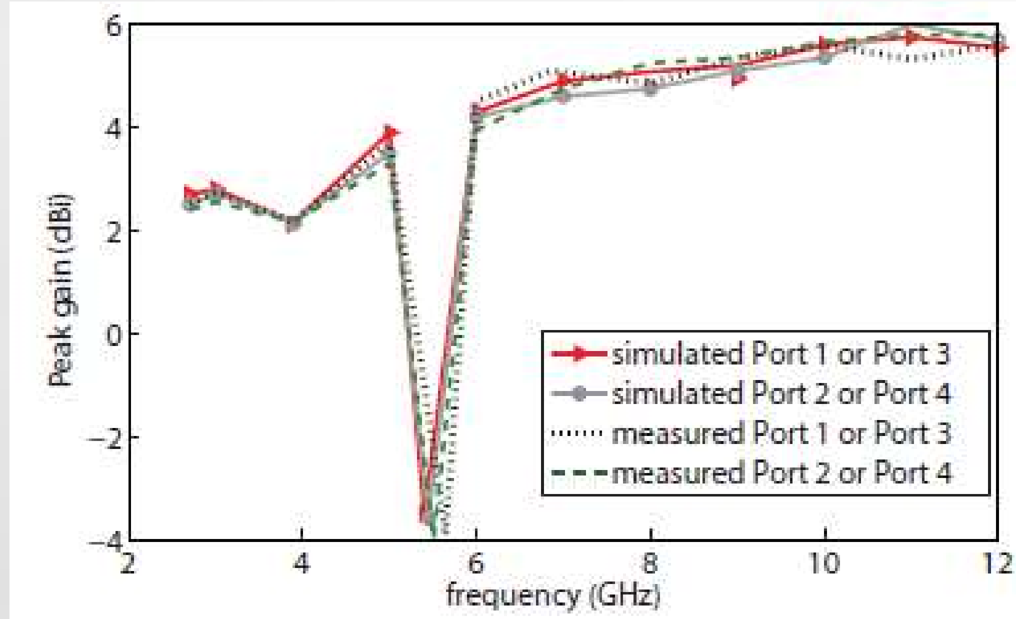
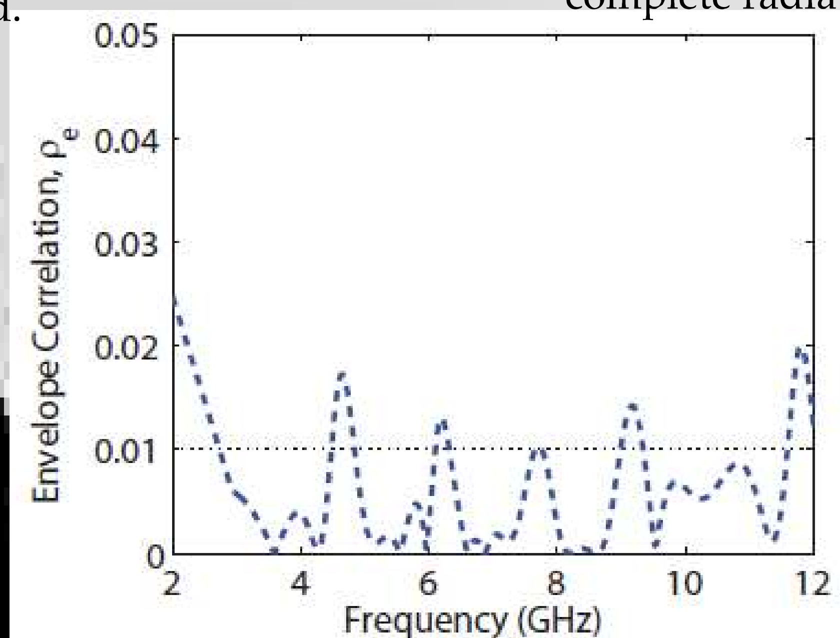


Figure : Simulated and measured peak gain of the proposed antenna for the PIN diodes biased state over complete radiating band.



[illegible]ted ECC from the measured S-parameters.

Proposed Design 4

➢ Four Elements Selflex array

- A reconfigurable sensing circuit to recover the pattern on conformal surfaces
- Resistors, AMP04 and flexible resistor were used to design the sensing circuit
- Input voltage was changed to [redacted]ange the output and enable [redacted] provide correct voltage [redacted]tching frequency.

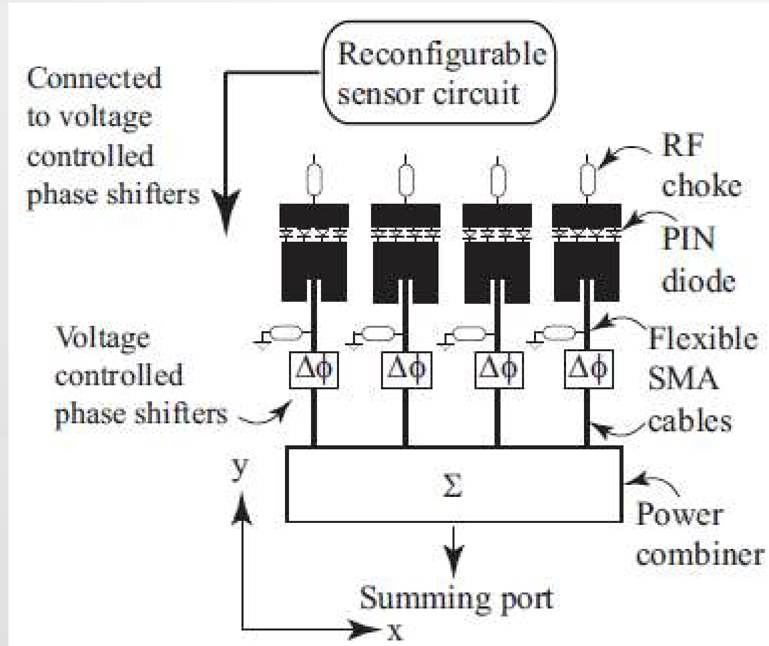
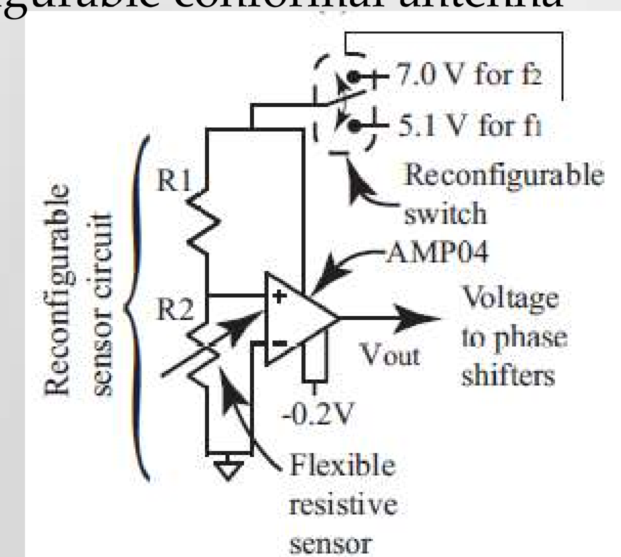


Figure: Topology of the self-adapting frequency reconfigurable conformal antenna



[redacted]le sensing circuit used to control the voltage controlled phase [redacted]onnected between pins 1 and 8).

Conformal Surfaces

$$\Delta z_w = L|n|sin\theta_b,\ 0 \le \theta_b \le \pi/2,\ (x_{\pm 2},\ z_{\pm 2})$$

$$\Delta\phi_{\pm 2} = k\Delta z_w$$

$$\Delta\phi^{w1}_{\pm 2} = k_1\Delta z_w \quad (2)$$

$$\Delta\phi^{w2}_{\pm 2} = k_2\Delta z_w \quad (3)$$

$$\Delta z_c = r|sin(\phi_n) - sin(\phi_{n-1})|$$

$$\Delta\phi^{c1}_{\pm 2} = k_1\Delta z_c$$

$$\Delta\phi^{c2}_{\pm 2} = k_2\Delta z_c$$

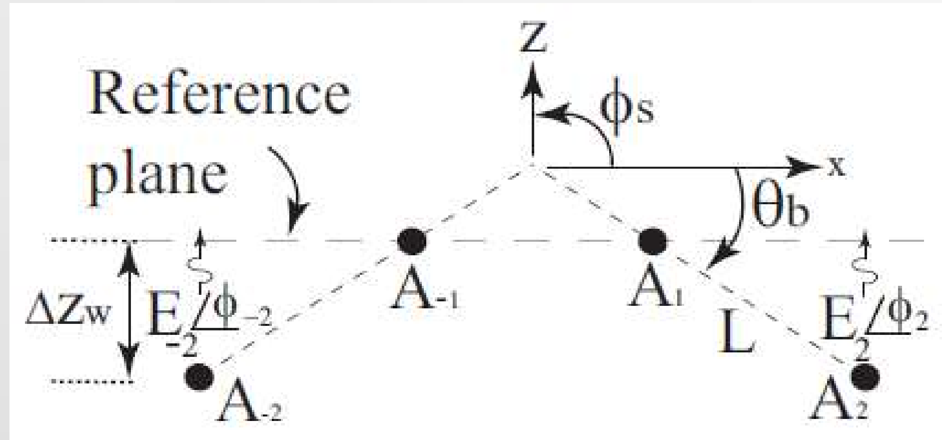


Figure: An illustration of a 1 x 4 array on a wedge-shaped conformal surface with a bend angle θ_b.

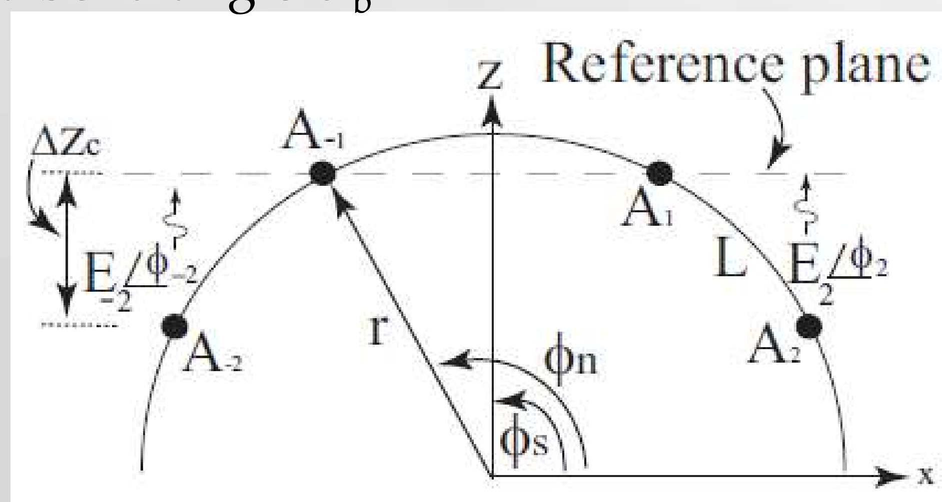
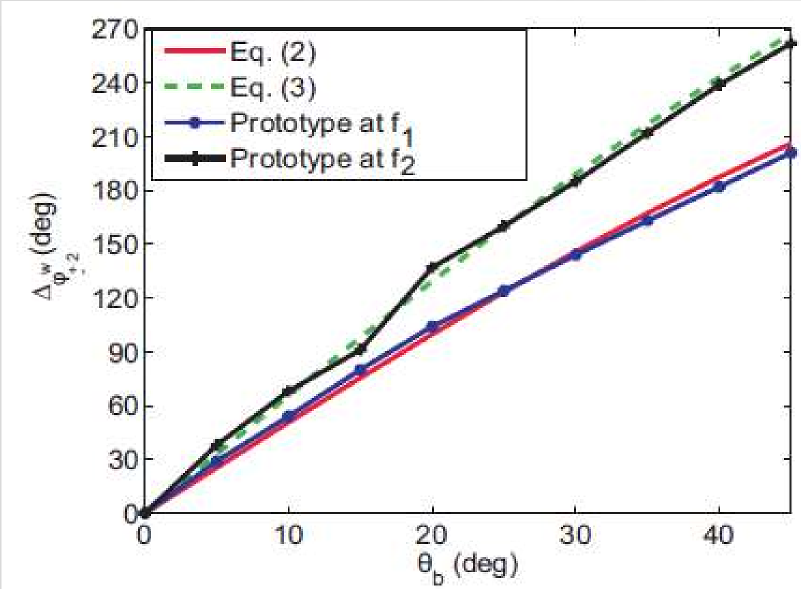


Figure: An illustration of a 1 x 4 array on a cylindrical-shaped conformal surface with a radius r.

Simulated and Measured Results



...re: Normalized phase shift values measured ... e Hittite phase shifters and compared to the ... termined by eqns. (2) and (3) for accuracy.

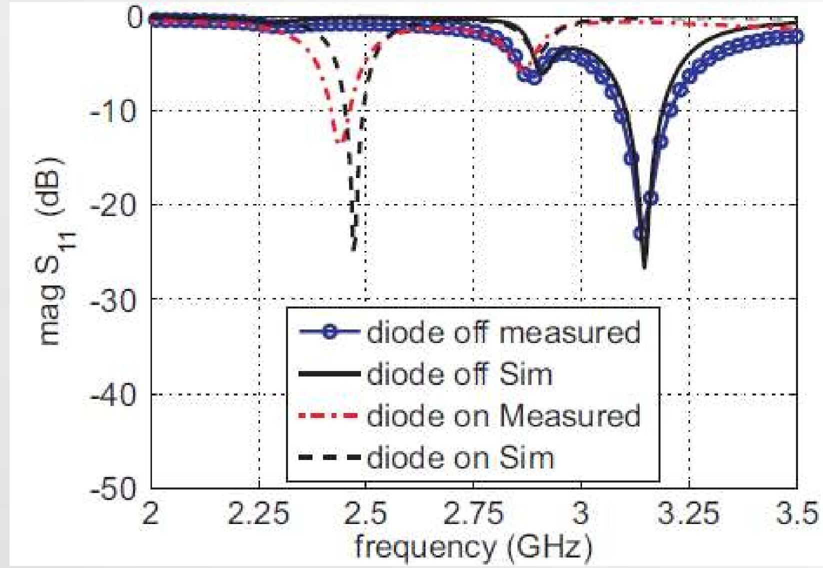


Figure: Measured and simulated S-parameter

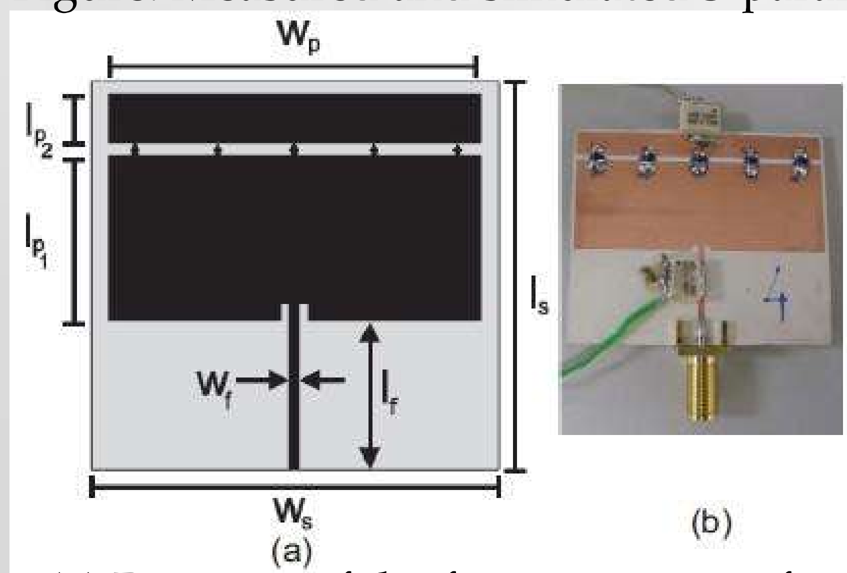
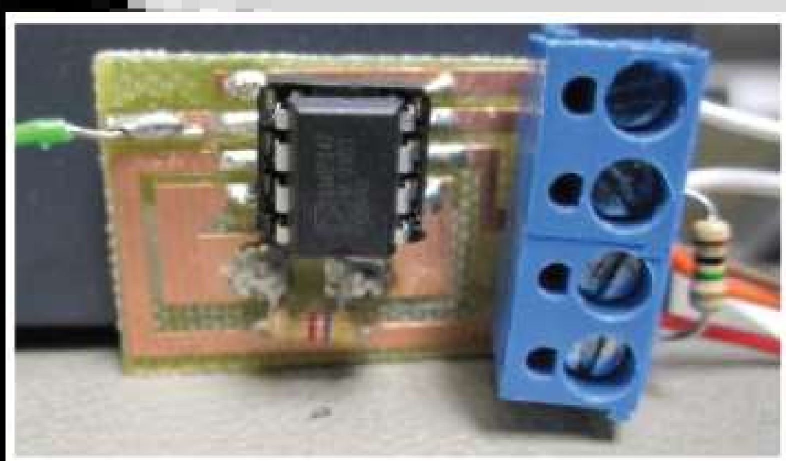


Figure: (a) Drawing of the frequency reconfigurable microstrip patch element in the 1 x 4 array and (b) photograph of the prototype element (l_s = 42 mm, w_s = 50.5 mm, l_{p1} = 17.7 mm, l_{p2} = 4.8 mm, w_p = 49 mm, l_f = 17.6 mm, w_f = 1.3 mm.



...ototype

Patterns on conformal surfaces

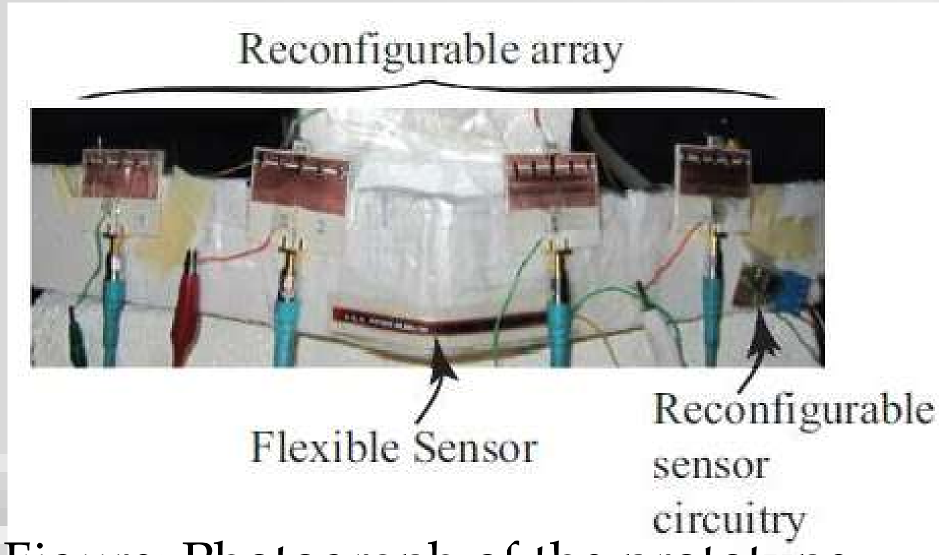


Figure: Photograph of the prototype
rray on the wedge-shaped conformal
ace.

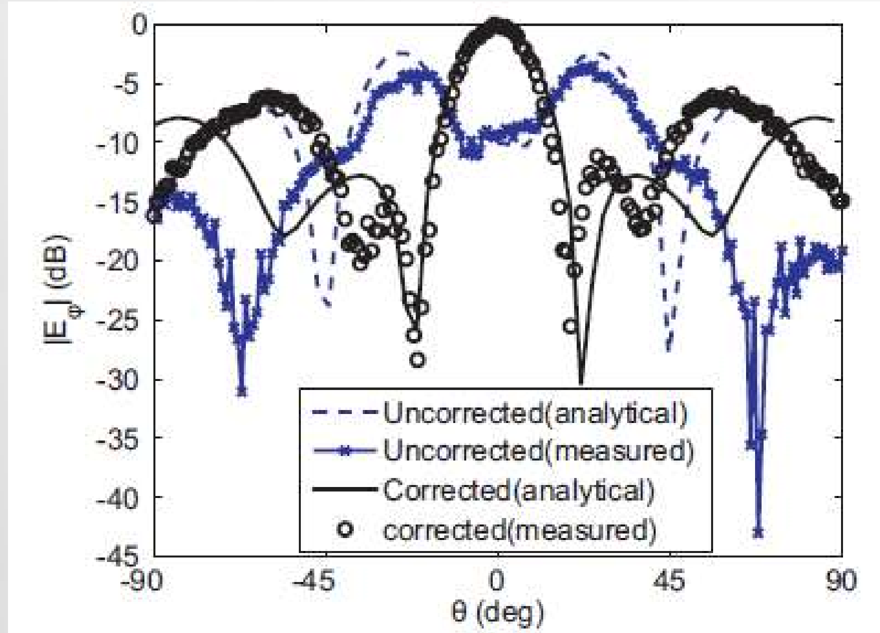
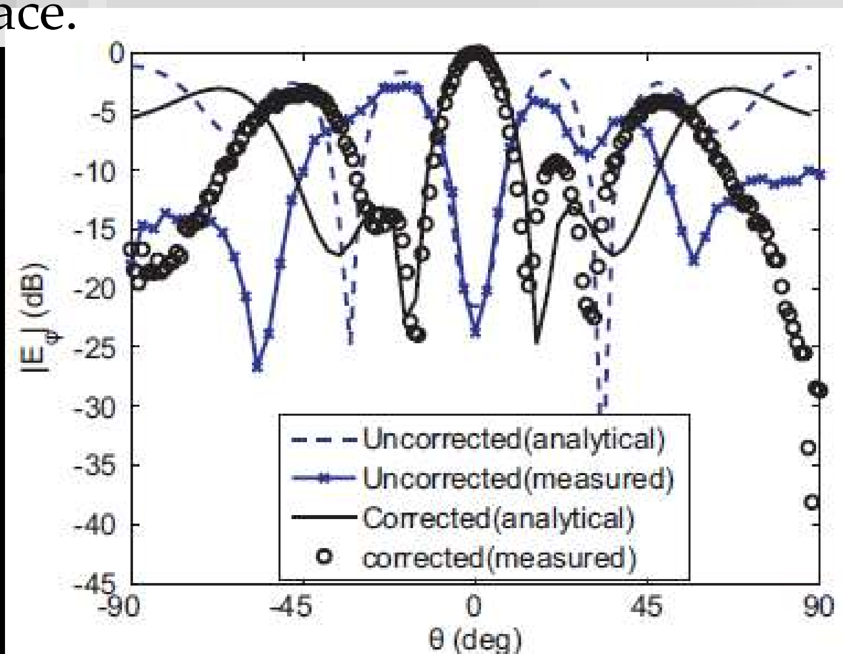
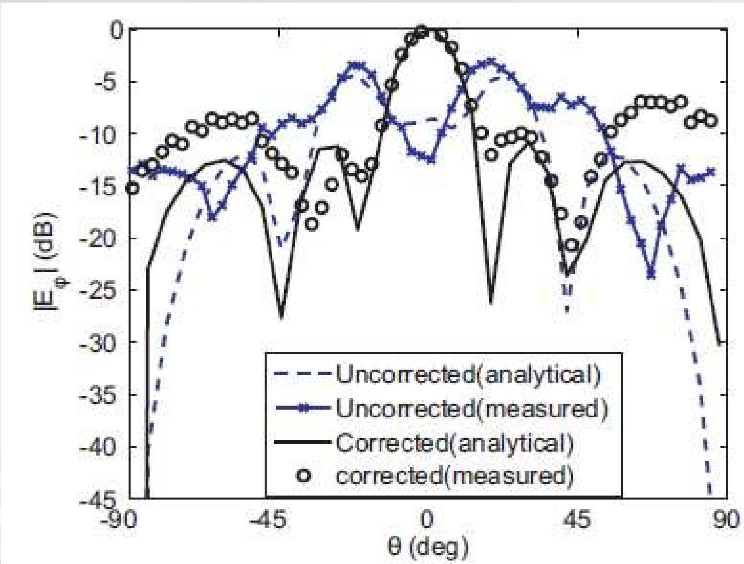


Figure: Analytical and Measured patterns of antenna array at 2.43 GHz (f_1) in the x-z plane for the wedge-shaped conformal surface with $\theta_b = 30^o$.



ed patterns of antenna array at 3.15 GHz (f_2) in
d conformal surface with $\theta_b = 30^o$

Patterns and Gain



...ure: Analytical and Measured patterns of ...nna array at 2.43 GHz (f_1) in the x-z plane ... cylindrical-shaped conformal surface.

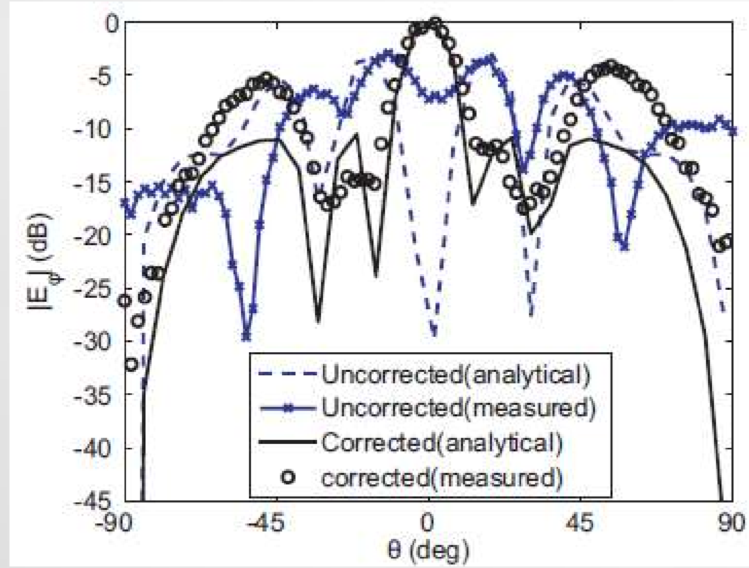
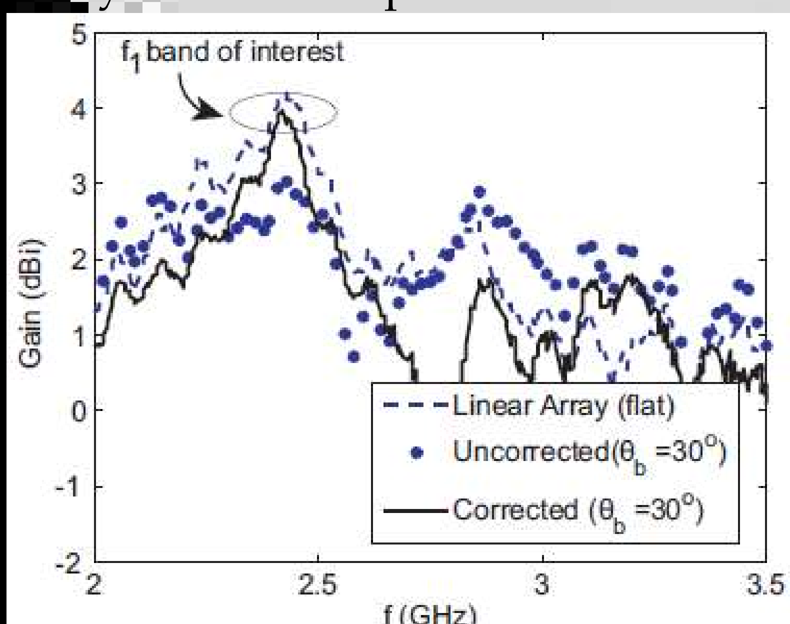


Figure: Analytical and Measured patterns of antenna array at 3.15 GHz (f_2) in the x-z plane for the cylindrical-shaped conformal surface.



...pting

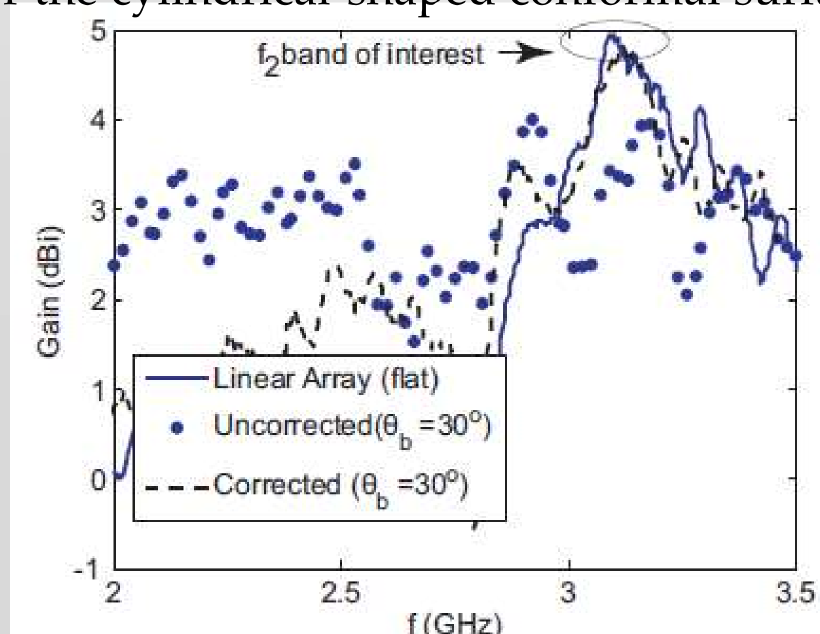
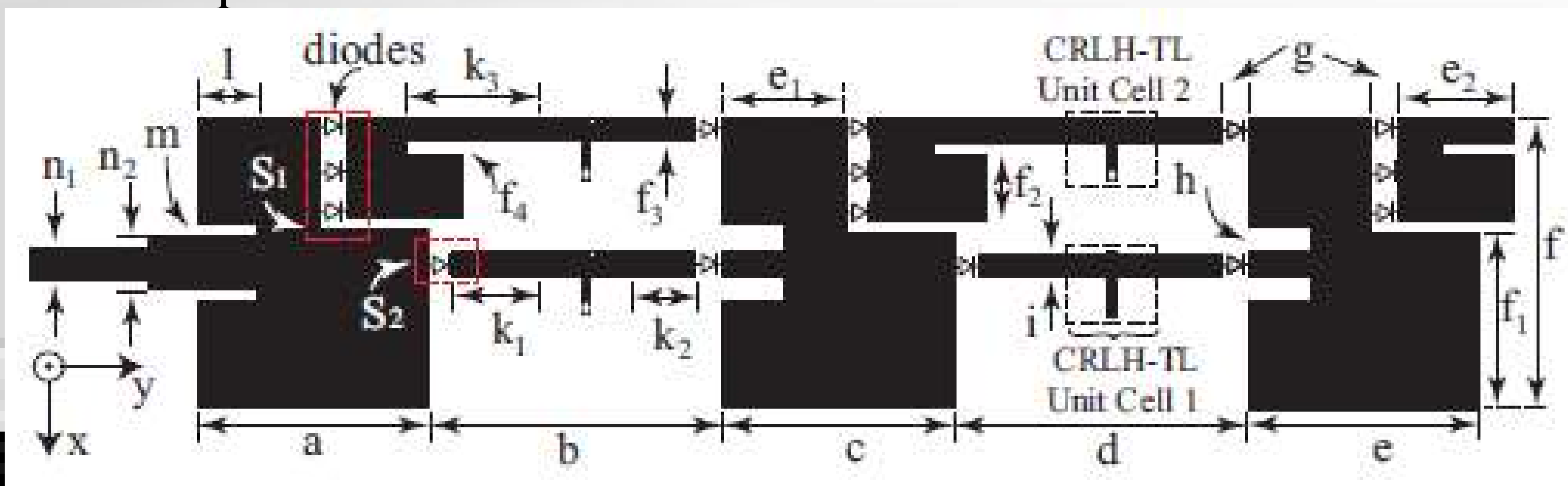


Figure: Measured gain of the self-adapting antenna prototypes at f_2 for $\theta_b = 30^o$.

Proposed Design 5

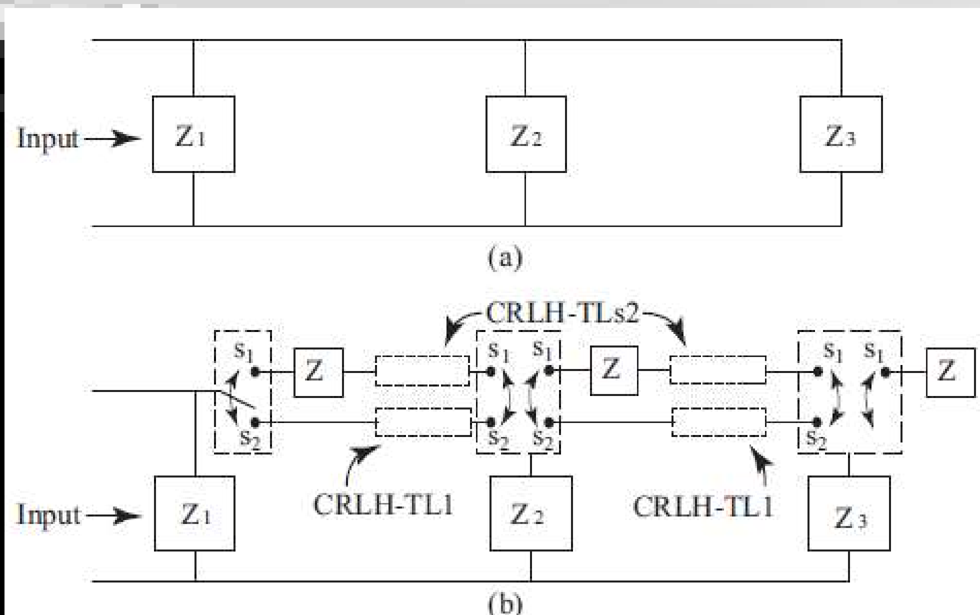
- **Series Fed Array with three elements**
  - Pin diodes are used to used to reconfigure the different CRLH-TLs for switching frequencies
  - The array switches from 2.37 GHz to 1.97 GHz
  - Broadside patterns are achieved at both switching frequencies



ayout of the reconfigurable series fed array with CRLH-TL interconnects. (a)
b) Bottom view. Dimensions are: a = 43.2 mm, b = 39 mm, c = 43.7 mm, d =
4 mm, f = 49.5 mm, f_1 = 26.5 mm, f_2 = 15.3 mm, f_3 = 2.7 mm, f_4 = 2.5 mm, e_1 =
5 mm, g = 1 mm, h = 2.65 mm, i = 2.7 mm, k_1 = 16.9 mm, k_2 = 8.2 mm, k_3 =
m, m = 2 mm, n_1 = 3.65 mm and n_2 = 4.86 mm.

Block Diagram

- Metamaterials exhibit certain electromagnetic properties which are not found in nature.
- Left handed materials having properties of negative permeability and permittivity
- Veselago in 1967 was the first physicist who realized the concepts of left handed materials (LHM).



… of a 3-element series-
… strip interconnects
… ement series-fed
… wing the

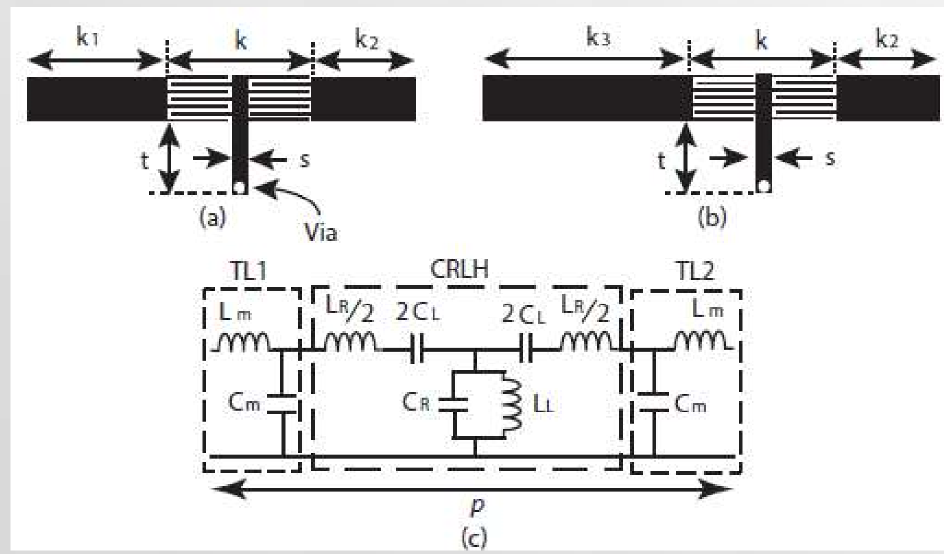
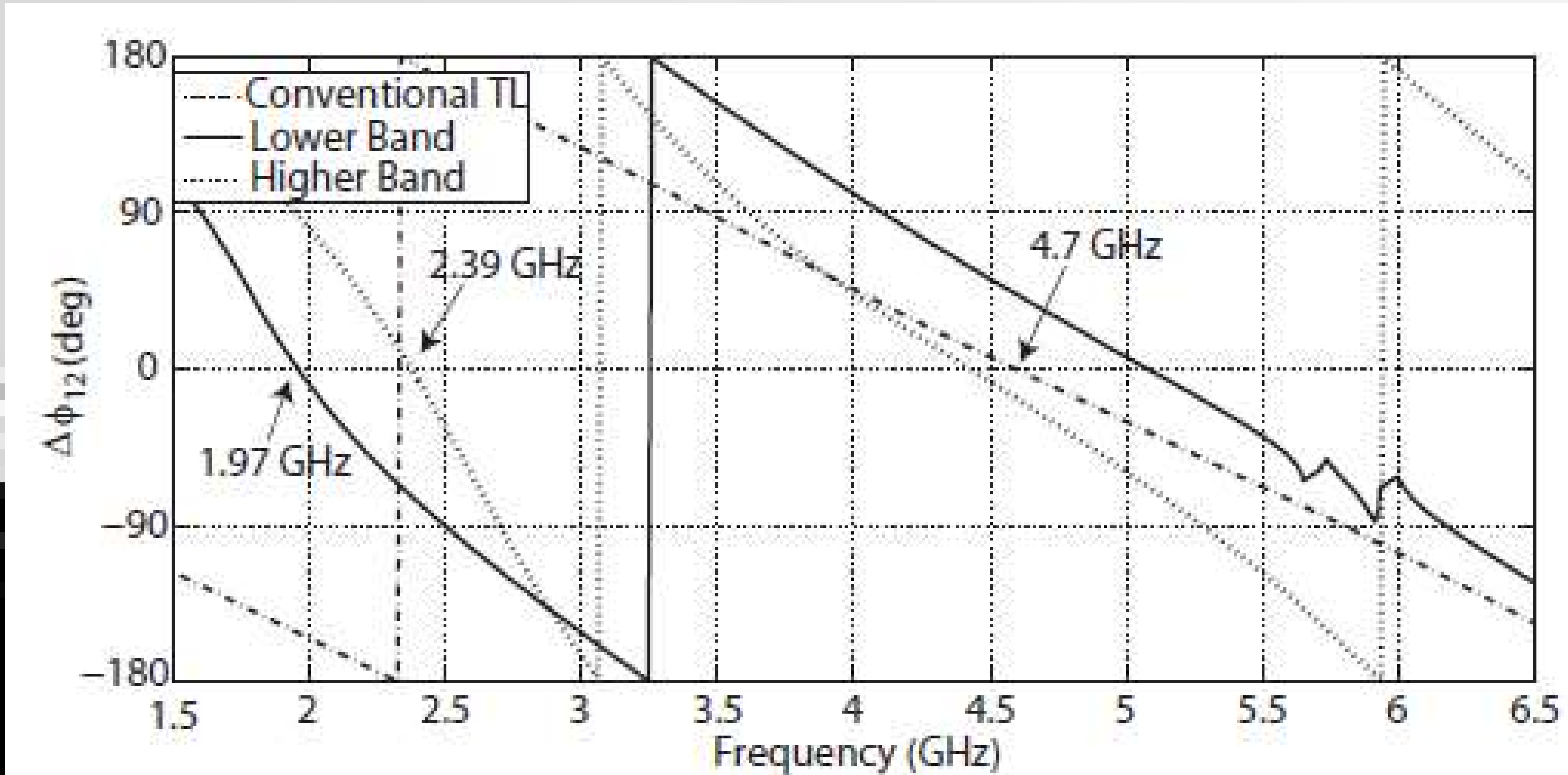


Figure: (a) Layout of CRLH-TL unit cell 1. (b) Layout of CRLH-TL unit cell 2. (c) Circuit representation of CRLH-TL Unit Cells. Dimensions are: $k = 11.9$ mm, $k_1 = 16.9$ mm, $k_2 = 8.2$ mm, $k_3 = 23.8$ mm, $S = 1.3$ mm, $t = 7.26$ mm.

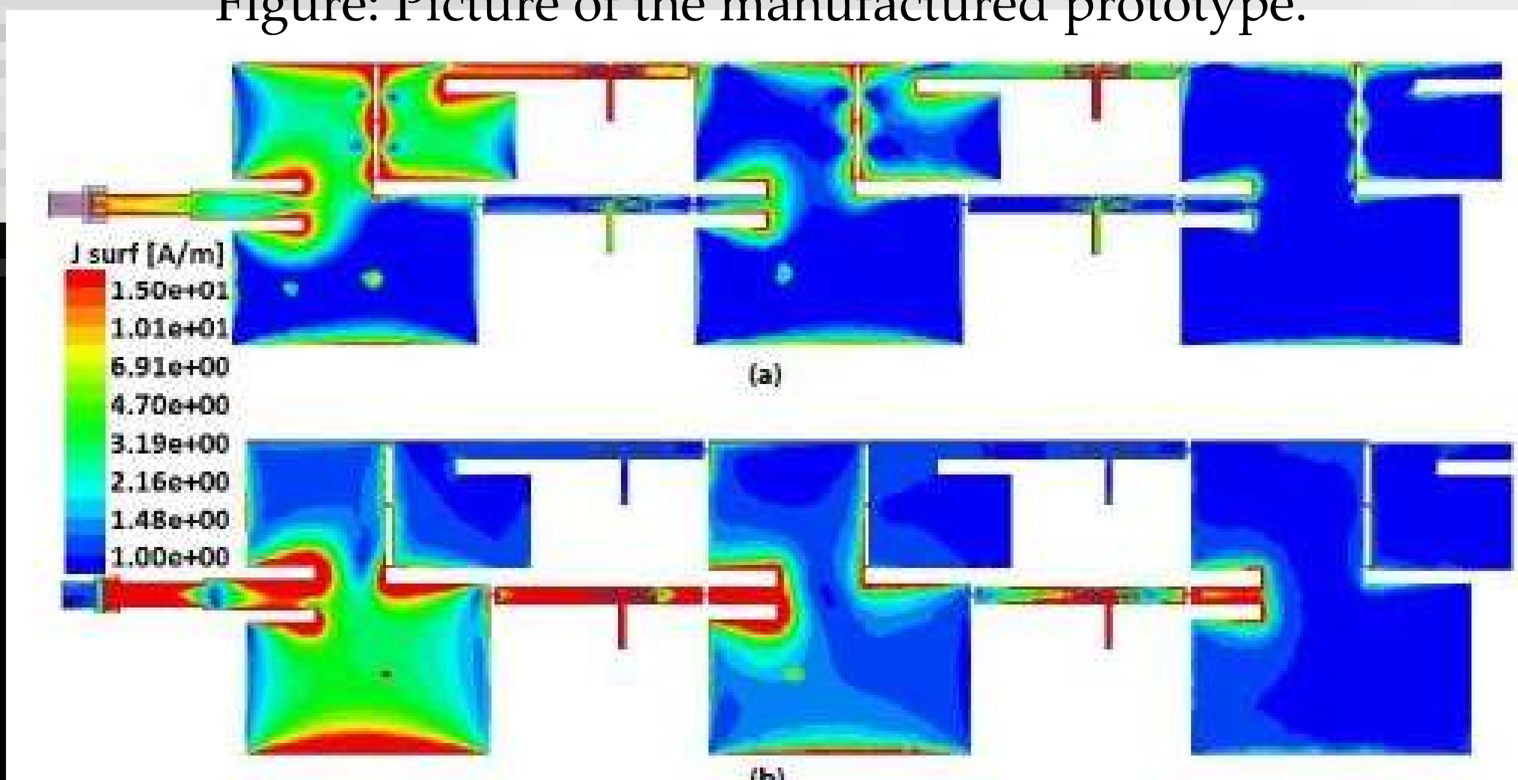
Zero Phase Diagram



S_{12} phase for the conventional transmission line with a
, higher band (unit cell 1) and lower band (unit cell 2).

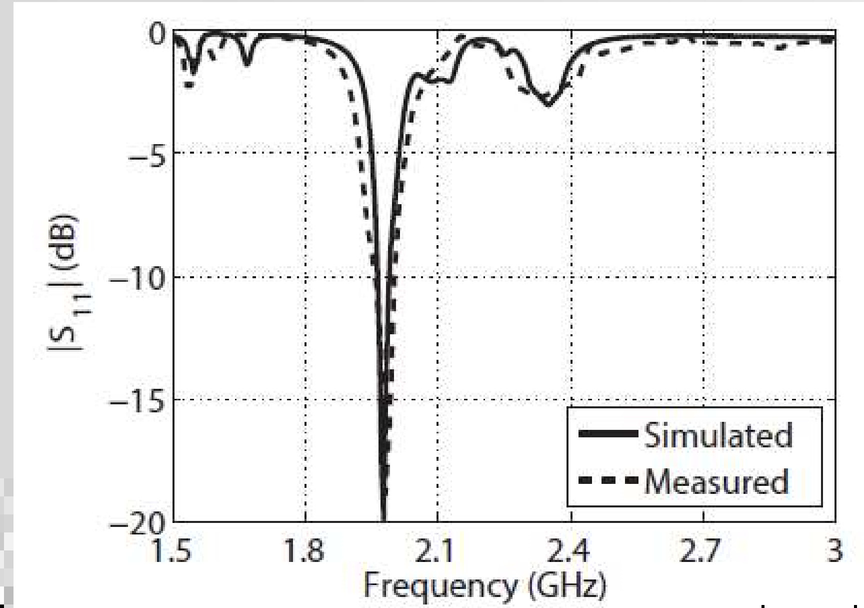
Surface Current

Figure: Picture of the manufactured prototype.



[redacted]stribution for (a) 1.97GHz and (b) 2.37GHz.

Simulated and Measured Results



[redacted]gure: Simulated and measured $|S_{11}|$ for [redacted]ower band with S_1 activated.

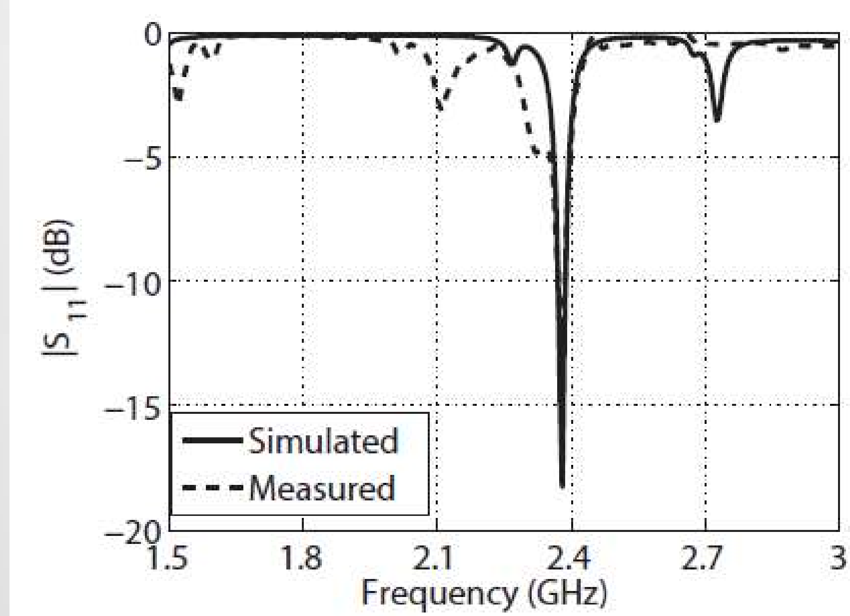
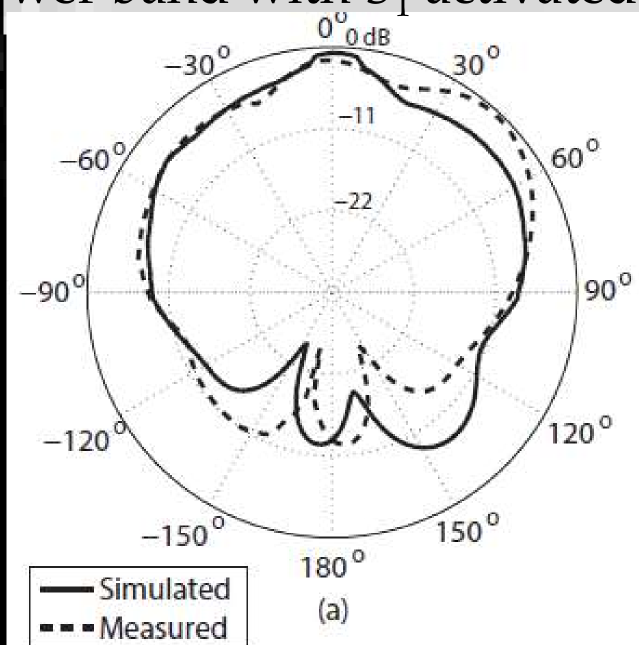
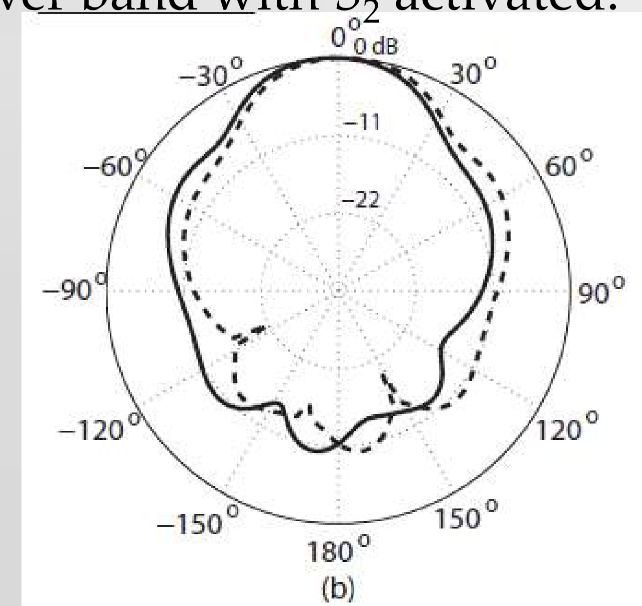


Figure: Simulated and measured $|S_{11}|$ for the lower band with S_2 activated.





- [redacted]n pattern in the y-z plane for (a) 1.97GHz and (b) 2.37GHz.

Conclusions

- Five different reconfigurable antennas are designed.
- Frequency reconfigurable antenna
- Two elements UWB-MIMO antenna with WLAN rejection
- Four elements UWB-MIMO antenna with WLAN rejection
- Frequency reconfigurable self adapting antenna array
- Three elements series fed array with CRLH-TLs

PIN diodes are used to reconfigure these antennas.

Challenges and Future Directions

- **Challenges**
  - Losses due to active elements
  - Power consumption due to active elements
  - Mismatch between simulated and measured results

- **Future Directions**
  - MEMS switches with fast switching and low input voltage
  - Magnetic switches
  - New applications (dual polarized omni-directional MIMO antennas)

Acknowledgement

- Cariparo Foundation
- Prof. Antonio Capobianco
- Prof. Benjamin Braaten

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Any Question?


Thank You!